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PRINCIPAL INVESTIGATOR: Adrian E. Park, MD

CONTRACTING ORGANIZATION: University of Maryland
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Adrian E. Park, MD

Email: apark@smail.umaryland.edu

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Introduction

During the past decade, we witnessed an extraordinary evolution in surgical care based upon rapid advances in technology and creative approaches to medicine. The increased speed and power of computer applications, the rise of visualization technologies related to imaging and image guidance, improvement in simulation-based technologies (tissue properties, tool-tissue interaction, graphics, haptics, etc) has caused an explosion in surgical advances. That said, we remain far behind scientists in applying information systems to patient care. This research effort has proceeded under the mantle of "Operating Room of the Future" research. We replaced that theme with the more appropriate "Innovations in the Surgical Environment."

The content of this Final Report contains information pertinent to continued activities in relation to the W81XWH-06-2-0057, "Advanced Technologies in Safe and Efficient Operating Rooms" project. This contract consists of a scope of work that fits seamlessly onto a prior research activity in the contract DAMD-17-03-2-0001, "Advanced technologies in safe and efficient operating rooms" work. The current research project activities are based upon three pillars of research, OR Informatics, Simulation for Training and Smart Image. A fourth research area was included in the Informatics pillar during this period of performance that targeted physical and cognitive ergonomics/human factors.

Two of the Informatics projects were closed last year. The Intra Perioperative Communication (IPC) project has been completed; the CAST project was replaced by the Video Summarization project. In the Simulation pillar, the Maryland Virtual Patient (MVP) project has been concluded other than for preparation of manuscripts and presentations. Other sources of funding for this project are being sought. Work continues on the other projects under the terms of a no-cost extension. Milestones and termination dates for these projects were projected and reported.

The past year of work focused upon conclusion of project work in Informatics, Ergonomics and Simulation. Additional publications were prepared and are presented in the Appendix to this report. The no-cost extension provided the research team the opportunity to develop a plan to carry forward "Innovations in the Surgical Environment" for the betterment of both patient and healthcare provider. The plan is reported herein.

Expansion of the Vision: Innovations in the Surgical Environment

On November 19, 2010, a distinguished group of surgeons, scientists, academicians and industry partners assembled in Baltimore, Maryland to consider the future actions associated with the Innovations in the Surgical Environment (ISE) conference. This conference had been convened annually for the previous six years in an effort to apply

advanced technology research to the perioperative environment. Heretofore, the program was supported by four targeted pillars of research: Informatics, Smart Instrumentation, Simulation and Ergonomics/Human Factors. The response of participants to this conference led the sponsors to believe that the meeting has extraordinary potential to meet unmet needs of the surgical and research communities. The agenda for this meeting and list of participants are presented in Appendix C.

Foundational Statement:

The ISE initiative was defined as a gathering comprised of experts from disparate fields to address the challenges facing surgeons and other healthcare professionals in the perioperative environment. The ultimate goal of ISE is to improve safety and outcomes of patients and caregivers within this environment. Collaborative, multidisciplinary efforts through the lenses/pillars of Surgical Visualization (smart image), Smart Instrument, Ergonomics/Human Factors, Simulation, and Bioinformatics will be among the focused efforts of ISE.

Strategic Imperatives – an Overview:

The foundational statement would provide the base from which the iterative and/or revolutionary dialog would evolve. A formal structure composed of any of the following—officers, a board, committees, a small cadre of permanent staff, and an executive director—to operationalize the function (i.e., define the mission) and the structure (i.e., execute the goals, support and extend events, serve as a clearinghouse for funding and development) of ISE should be put into place. Relevant stakeholders/constituents (e.g., representative of boundary crossing – academic, entrepreneurial, military, regulatory, applied and theoretical scientists and/or technicians, organizations as diverse as IEEE and AORN) must be invested/involved. An overall framework should be identified to provide ISE focus in terms of addressing innovative issues and solutions. A very significant effort needs to be expended in regard to correctly branding ISE so that its transformative vision is captured. The "problem space" must be identified, then the issue that occupies it defined, followed by characterization of the components of the topic. The creation of an innovative clinical culture, including the setting of standards, must be fostered.

It was proposed that the ISE initiative be carried forward through a series of operational activities that involved continuous planning, engagement with industry, academia and government, formal organization and efforts to obtain funding. Strategic thinking was applied to the preparation of annual conference with focused workshops with targeted goals subject to the scrutiny of expert panels. The innovative process would address the questions of whether ISE can create a structured, adaptable implementation process for innovation, whether ISE can shepherd a project from *conception* to *clinical implementation* (which would require ISE possess capabilities to mitigate or remove obstacles such as funding, clinician acceptance, regulatory requirements, etc.), and whether ISE should —rather than addressing the "full research process"—content itself

with harvesting technology components, in particular basic uncomplicated components that in the main are related to emerging technologies?

Among other considerations, the group considered factors of evaluative standards and relevancy. Evaluative standards would be set by the ISE in regard to assessment of innovation (such as measuring changes in process rather than changes in outcome—a strategy that might transform the common denial of bad outcomes). Such standards could also refer to those by which ISE rates and understands its own performance. Relevancy would be established by seeking to become the overseer of innovation and improvement for a politically established organization such as IOM. Alternative actions to maintain relevancy included becoming the focal point of a network of professional associations and thus facilitate cross-society pollination and collaboration to an ultimate end as beneficiary of the research efforts, or ISE alignment with a hot topic such as health IT, the current national focus, and attempt to leverage surgical innovation with smart health prevention and prediction.

The distinguished participants were distributed into expert panels for consideration of ideas and for development of recommendations. A summary of workgroup deliberations is presented in Appendix D.

Body

A. OR Informatics

The technological development of medical informatics has had profound impact upon improvements in the delivery of patient care. Two publications prepared by this research team exemplify how that impact is achieved. These publications are presented in Appendices A and B.

Informatics subgroup 1. Workflow and Operations Research for Quality (WORQ)

The Perioperative Scheduling Study studied how using post-operative destination information during the process of surgery scheduling can influence congestion in postoperative units such as ICUs and IMCs, which lead to overnight boarders in the PACU. The research team was composed of Jeffrey W. Herrmann, Ph.D., and Greg Brown, a graduate student, both with the University of Maryland, College Park. The team worked closely with Michael Harrington, Ramon Konewko, R.N., and Paul Nagy, Ph.D., for guidance and assistance. This research was summarized in a Ph.D. Preliminary Oral Exam, entitled The Surgery Scheduling Problem, Block Release Policies, and Operations Research Applied to Health Care; by William Herring under the mentorship of Dr. Hermann.

We have developed a mathematical evaluation model for evaluating congestion in post-operative units, including ICUs, IMCs, and floor units. This model requires data about post-operative destinations and length-of-stay distributions for different types of

surgeries. We have analyzed data about cardiac surgeries from two years and have analyzed UMMC financial records for all of the surgical cases for fiscal year 2007. We developed an algorithm for predicting bed requirements based on the surgical schedule and have conducted a preliminary study comparing these predictions to other prediction methods for two units. The preliminary results show that the new bed requirements prediction method is more accurate. We plan to complete the study and document the results in a technical report this fall. We continue to refine and implement mathematical models for evaluating how different block release policies affect OR utilization and staff overtime.

A summary of doctoral level work performed by William Herring in support of this project is included here. During the Spring 2009 semester, he conducted a thorough review of the operations research literature on operating room (OR) scheduling. In the course of this review he came across what is believed to be a critical and understudied interaction that has been the focus of research since then. For many hospitals, including UMMC, the initial stage of the surgery scheduling process is the allocation of available operating room blocks to different surgical service lines. However, as the schedule for a given day evolves, focus shifts to individual patients and a new set of challenges present themselves to operating room managers.

A great deal of research has been conducted on algorithms for scheduling individual patients into available operating room space, and in recent years a good deal of attention has been paid to determining the best ways to allocate operating room blocks. However, very little work has been done on the interaction between these two pieces of the scheduling puzzle. In order to systematically explore the policies that affect this interaction, Herring worked closely with members of UMMC's perioperative staff to observe all stages of the scheduling process and develop a model for how the process evolves as the day of surgery approaches. In developing this model, he determined that the key policies that control this interaction are the block release policy (when OR managers take unused space back from individual service lines) and the request queue placement policies (how this space is used).

Herring developed a stochastic dynamic programming (SDP) formulation of the single day surgery scheduling problem which incorporates the block schedule and allows for flexibility in setting and testing the effectiveness of different block release and request queue policies. A key component of the formulation is the arrival process for the demand for OR space (both the quantity *and* the timing of the demand). In order to estimate this demand, Herring worked to get access to data from UMMC's CDR and went through a training course on pulling data tables from the Clinical Data repository (CDR). Also, because the optimal policy suggested by the SDP formulation might not be practical from a OR manager's perspective, he developed a simpler decision-making model which more closely reflects how request queue decisions are currently made.

In September, he wrote a computer program that solves small instances of the SDP and began exploring the types of policies that the model suggests. In order to compare the optimal policies suggested by the SDP with more practical policies, the program is

flexible enough to accept policy constraints and only produce solutions that operate within those constraints. Since he did not yet have accurate estimates of the demand for surgery, these initial runs were done with simple demand distributions and tested the formulation's sensitivity to different types of distributions.

Herring's completed dissertation reported a model for the surgery scheduling process for a large operating room (OR) suite, a problem which involves decision-making in a highly stochastic environment. A typical modeling approach for this type of problem is to use what is known as a Markov decision process (MDP) to analyze scheduling decisions.

Informatics subgroup 2. Operating Room Glitch Analysis (OGA)

The OGA project, focusing on institutional learning, examined the workflow around performance indicators in the perioperative environment and building a graphical dashboard to allow data mining and trend analysis of operating indicators.

The dashboard was constructed using the Ruby on Rails web development platform with a MySQL database dynamically driving the queries. An interactive graphical dashboard provided synthesis around delays in operations with multiple information visualization techniques.

The initial surgical dashboard provided a strategic view of the department. An extension of the data warehousing layer is an observation engine which, when user specified events occur, will trigger processes ranging from communication (telecom, email, etc) to information exchange with other applications via web services. The user interface contains three major components: 1) A data manipulation layer which allows interaction with the data warehouse and provides analysts with means to create and track new metrics; 2) A visualization toolkit to create graphs and web pages to display information effectively. This includes the means to create clickable and animated graphs; and 3) A simplified means to specify observers within the business intelligence engine and canned solutions to communication information when events occur.

Objective 1.
Complete a business intelligence engine to handle aggregation and manipulation of data. Future work will entail the refinement of dashboards currently in beta testing.

To accommodate the need for data validation as well as tactical information about OR use from day to day an additional dashboard was developed. This dashboard was designed to focus on case to case problems of the perioperative environment. A greater scrutiny of daily performance and case data will drive the questions asked of the strategic dashboard which remains in beta testing. During the year of this report, the following work was completed. A tactical dashboard was developed in conjunction with the strategic dashboard and has been deployed to an internally hosted server. The tactical dashboard is being used within the perioperative environment to evaluate OR utilization, scheduling workflow, and case data accuracy. Data are being validated at the case level and new processes for data entry are being designed to ensure the accuracy of the metrics within the strategic dashboard. A semantic relationship query mechanism to facilitate

ubiquitous, dynamic filtering of data was developed for the strategic dashboard. The strategic dashboard's user interface has been updated to include an initial design for filtering of information as well as a means to create dashboards. The perioperative data are being validated through the use of the use of the tactical dashboard. This validation is necessary before the release of the strategic dashboard as poor data quality causes inaccuracies in aggregated statistics.

Informatics subgroup 2. Ergonomics/Human Factors

Additionally, within our established informatics research, for over two years we have continually identified the emergence of *Ergonomics/Human Factors(E/HF)* as a major sub-component interest within the existing aims of our contract. As research progressed with the overall Innovations in the Surgical Environment program and in particular with the Informatics pillar, attention was drawn to the importance of these factors to patient safety and effective training in surgical procedures. This emergence of these areas of interest and subsequent investigation of ergonomics/human factors has been consistently and formally reported in two of our annual conferences and most recently in quarterly and annual reports to USAMRMC. Several manuscripts related to our research in ergonomics and human factors were published during the past year.

Human factors and Ergonomics are two related branches of study that examine the relationship between people and their work environment. Ergonomics often focuses on the physical environment and the human body, while human factors center more on the cognitive aspects of performance—how an operator interacts with the information environment. The same ergonomics and human factors techniques credited with making industrial processes safer and more efficient can be applied to the analysis and improvement of OR operations.

Our Informatics research pillar comprises and subsumes the investigation of ergonomics and human factors. To this point, our discussion of workflow has taken a macro or panoramic view; for example, how might we most effectively track and bring together the people and assets necessary to ensure that a patient's surgical experience is safe and efficient. Through our formal recognition of human factors and ergonomics within our existing research pillars, we focus on a more micro-level analysis, such as how the physical interface between the surgeon and the patient could be improved and the associated work space chaos and stressors of minimally invasive surgery (MIS) be reduced.

The patient is the center of the ORF. During MIS, the interfaces between the patient and the surgeon are critical to both the safety and quality of patient care and surgeon welfare. Patient-surgeon interfaces are complicated by compromises in equipment design, technology limitations, operating theatre layout, and technical approaches. In particular, ergonomic problems in the MIS workspace, such as obstructing catheters and cluttering tubes, can elevate the chance for contamination, increase surgical risks to the patient, and

reduce work efficiency. Optimal workflow during MIS stands to be achieved through better understanding of patient-surgeon interfaces, both intracorporeal and extracorporeal. In the ORF, advanced technology could function as a key enabler, allowing an optimal patient-surgeon interface.

Some of our current work is focused on establishing quantitative, valid measures of workflow within patient-surgeon interfaces, identifying ergonomic problems that result as a consequence of workplace designs (e.g., arrangement or management of cables and catheters), and demonstrating key barriers to optimal workflow that present direct safety and efficiency concerns. One project is based on collaboration between surgical experts and human factors experts. Previous experiences in video capturing and analysis are being used as a basis for development of workflow measures and identification of ergonomic inadequacies. Time-motion studies have been conducted to collect objective data on activities in the patient-surgeon interface. Conceptual workplace layout designs are being developed based on objective data and simulations of what workflow might be if interfaces were optimized.

Given the physical risks associated with performing laparoscopic surgery, ergonomics to date has focused on the primary minimally invasive surgeon. Similar studies have not extended to other operating room staff. Simulation of the assistant's role as camera holder and retractor during a Nissen fundoplication allowed investigation of the ergonomic risks involved in these tasks. Specific tasks to be completed in support of this research were identified as objectives of the study.

Objective 1. Continue to develop an assessment of difficulty hierarchy of Fundamentals of laparoscopic Surgery (FLS) tasks. This task will require extended work.

Objective 2. Develop an assessment of the effectiveness of self-mentored surgical training. We realized the importance of the fundamental understanding about the characteristics of the movement patterns utilized by expert laparoscopic surgeons. For the early stage of this particular research project, we have started establishing quantitative and objective methodologies to identify these expert movement patterns which must be substantially different than the movement patterns used by less experienced surgeons. We are also in the process of defining finite numbers of sub-movements which may create complex surgical movements by successive combination of several sub-movements.

Informatics subgroup 3. Context Aware Surgical Training (CAST)

We proposed to design and implement a prototype context aware surgical training environment (CAST) as part of the University of Maryland Medical System's SimCenter. This system was designed to explore the role that an intelligent pervasive computing environment can play to enhance the training of surgical students, residents and specialists. The research built upon prior work on context aware "smart spaces" done at UMBC; leverage our experience in working with RFID in the DARPA Trauma Pod program as well as in incorporating Web-based infrastructure and software applications in academic and professional development programs. The project was expected to result in a pilot system integrating one or two training resources available in the SimCenter into

a context aware training environment that can recognize the presence of a trainee and or mentor and take appropriate action based on known training goals and parameters. The project proposed to advance the knowledge of context aware training environments in a highly technical medical field and provide a basis for incorporating more advanced technology assisted learning experiences in medicine. This "smart environment" may then, if successful, be scaled to meet the needs of an operative environment where the technological demands may be the similar or analogous to those seen in the training environment. Ultimately, the advanced training and potential for use in perioperative environments have a long-term end goal of improving patient safety and adding to the body of knowledge in surgical training. Initially, we saw a situation were clinicians in training can receive a tailored curriculum. Additionally, we envisioned a system that offers real-time feedback and decision support and education metrics to faculty.

A key goal this year was to prototype the CAST system, and we defined a typical use case for our system. A Student enters the simulation center. The system identifies the student (for instance, using their Bluetooth phone or their badge), and does a prerequisite check based on the simulator the student wants to perform the procedure. Only if the student is done with the prerequisites, is he/she allowed to proceed. When the student indicates that they are ready to begin, the system starts capturing the external and internal view until the student indicates that they have completed the task. The captured video is then transferred to the video server for review by the instructor. The instructor interface allows the instructor to see the entry logs of students in terms of when they entered and exited the center along with the corresponding external view.

We employed the spiral prototyping approach as an experimental test bed; we designed and implemented an initial system prototype that would meet the above functional requirements. The prototype integrates two machines with each simulator -- a small Nokia 800 device for resident interaction, and a larger PC for video capture. Note that this is for the proof of concept. A single small form factor but computationally powerful machine could be used instead. In fact, for virtual reality (VR) simulators we expect that manufacturers could eventually integrate our system directly into the computer that drives the simulation.

Our prototype used Bluetooth for localization of residents in the simulation center. It was designed to be modular, so that any other technology (such as resident ID cards) could be integrated easily. We also hosted training materials including videos for FLS, Kentucky and Rosser tasks in our system, and tracked student progress through the chapters checked out. This was used for enforcing prerequisites when students entered the simulation centre to perform procedures. In addition to enforcing prerequisites, there was a need for the instructors to visually see what the residents were doing during their simulation procedures. We use N800's built in camera to capture the residents' external views. These video feeds are then fed into a central server for review by the instructor.

For location detection, we also experimented with using the Awarepoint tags. Awarepoint uses a zigbee based mesh network for localization and exposes the location information through a web service. Our experiments indicated that Awarepoint could provide us room

level information, but not anything finer. While this would help identify if the residents were in the simulation center, it would not help determine which machine they were using, which was needed for CAST. We demonstrated our first system prototype at the ORF workshop by going through a typical student workflow.

We also focused on moving the system from UMBC machines to the MASTRI infrastructure where they will be housed. We purchased a small factor Dell machine to be used for capturing internal views from simulators. Storage was purchased and added to the mastri-internal server for archiving both internal and external video feeds. Also, we have integrated the student database from the hospital, hosted FLS and other training videos on the hospital infrastructure and hacked internal views of the simulators. We developed the system to capture internal video feeds and metrics from the following simulators; Promis, Stryker and the Laproscopic VR simulator.

Current efforts have focused on testing an initial deployment of the CAST system at the MASTRI Center. We demonstrated the system to a set of resident volunteers for feedback in a form of Beta-test of the system. We set up hardware and software to include the VR Simulator as part of the CAST system deployment. We got usability feedback and fixed bugs. A significant part of the effort was also spent in surveying the state-of-the-art in Video/VR usage for surgical training. We identified a small but significant body of work (e.g. Sinanan et al, Darzi et al) in checking the construct validity of the models for training using these simulation tools. The typical approach is to use sensors to capture the kinematics of the tools, as well as force/torque measures. The UMBC/MASTRI team decided that we would like to focus on an alternate approach that i) focused on the video, not (initially) any other sensors and ii) tried to capture using machine learning techniques the ability of an expert surgeon to identify key events in a surgery that relate to outcome or skill assessment. This is a very challenging and open problem. Key initial steps were identified for initial implementation in the first year.

A detailed description of the CAST project, “A Ubiquitous Context-Aware Environment for Surgical Training”, was presented at the First International Workshop on Mobile and Ubiquitous Context Aware Systems and Applications (MUBICA 2007), August 2007, by P. Ordóñez, P. Kodeswaran, V. Korolev, W. Li, O. Walavalkar, B. Elgamil, A. Joshi, T. Finin, Y. Yesha, I.George.

NOTE:

The effort to establish a system for archiving imaged data from training sites has been attenuated due to advancements in archiving capability in off-the-shelf systems. The focus of this project now rightly shifts to video summarization by unique application of artificial intelligence techniques. Video summarization has extraordinary potential for streamlining the events in the future perioperative environment. Further, there are many and varied military applications from video summarization. The UMBC Graduate students currently working on the CAST and the background research effort for the new direction transitioned out, as the new direction is less closely aligned with their research

interests. Dr. Mike Grasso, MD/PhD in Computer Science, joined the effort, and a new graduate student whose research focus will be on the video efforts joined the team.

Informatics subgroup 3. Video Summarization

Our overall goal is to identity key portions of surgical procedures to aid in video-based assessment. To establish feasibility, we set out to identify the critical view of a laparoscopic cholecystectomy. The critical view is used to identify the key anatomy after major dissecting has been completed, but before clipping the cystic duct and artery.

During the past year, we completed an initial analysis of this problem. We compared more than 50 image features with a distance metric to identify the critical view of a laparoscopic cholecystectomy. We experimented with roughly 50 different images features and several distance metrics. Our initial results showed a 72% sensitivity and 72% specificity. The study was small in size, using only 5 laparoscopic cases, and our comparisons were limited to one image feature at a time. An abstract was submitted to the American Medical Informatics Association (AMIA) Fall Symposium (appendicized).

During the last several months, we have been working two new initiatives. The first is the creation of an image classifier using a support vector machine (SVM). This is a machine learning approach that uses multiple image features to train the image classifier. Our initial accuracy with the SVM improved to about 90%. This original SVM was built from only 5 laparoscopic cases. Our understanding is that 25 additional cases will be available after IRB approval has been obtained. Accuracy should improve when more cases are used to train the SVM. In addition, we used particle analysis and edge detection to identify key segments inside each image. We also plan to use this data to increase the accuracy of the SVM. During this past year, we prepared a protocol for the use of 25 additional video cases upon which to build the SVM.

Informatics subgroup 4. Operating Room Clutter (ORC)

The Operating Room Clutter project enters its final phase under the provisions of the contract, and ended during the period of performance reported here. Further research activities will seek support from other funding agencies.

Prior to completion, the project team worked on the use of advanced video technology to support coordination in operating rooms. Activities were in four areas. All publications referred to may be found in the website: http://hfrp.umaryland.edu. For full length journal articles, PDF files may be downloaded. For others, abstracts are available. In all, we published 8 full-length peer reviewed journal articles, 2 full-length peer reviewed proceeding articles, and 8 conference abstracts. The references below can provide further details.

A. Models of decision making for operating room management.

We reviewed literature and developed a synthesis report on the state of the art of decisions on the day of surgery. Furthermore, we developed models for decision support systems for operating room management. The activities in this area were reported in the following publication:

1. Dexter F, Xiao Y, Dow AJ, Strader MM, Ho D, Wachtel RE. Coordination of Appointments for Anesthesia Care Outside of Operating Rooms Using an Enterprise Wide Scheduling System. *Anesthesia and Analgesia. 105:1701-1710. 2007*

B. Operating room multimedia system design and methodology.
We developed technology, primarily based on algorithms of video processing and biosignal processing, to display status of operating rooms. The displays are to increase situational awareness. The technological advances made by our group were reported in the following publications:

2. Xiao Y, Schimpff S, Mackenzie CF, Merrell R, Entin E, Voigt R, Jarrell B. Video Technology to Advance Safety in the Operating Room and Perioperative Environment. *Surgical Innovation. 14(1): 52-61. 2007*

3. Hu P, Xiao Y, Ho D, Mackenzie CF, Hu H, Voigt R, Martz D. Advanced Visualization Platform for Surgical Operating Room Coordination: Distributed Video Board System**.** *Surgical Innovation. 13(2):129-135. 2006*

4. Hu P, Seagull FJ, Mackenzie CF, Seebode S, Brooks T, XiaoY. Techniques for Ensuring Privacy in Real-Time and Retrospective Use of Video. *Telemedicine and e-Health, 12(2): 204, T1E1. 2006*

C. Survey and descriptive studies of operating room management, with and without the support of advanced video technology.
In conjunction with technology development, we conducted observational and survey studies of operating room management. These studies and associated results were in the following publications:

5. Seagull FJ, Xiao Y, & Plasters C. Information Accuracy and Sampling Effort: A Field Study of Surgical Scheduling Coordination**.** *IEEE Transactions on Systems, Man, and Cybernetics, Part A:Systems and Humans. 24(6), 764-771. 2004*

6. Dutton R, Hu PF, Mackenzie CF, Seebode S, Xiao Y. A Continuous Video Buffering System for Recording Unscheduled Medical Procedures. *Anesthesiology, 103:A1241. 2005*

7. Gilbert TB, Hu PF, Martz DG, Jacobs J, Xiao Y**.** Utilization of Status Monitoring Video for OR Management. *Anesthesiology, 103:A1263. 2005*

8. Dutton R, Hu P, Seagull FJ, Scalea T, Xiao Y, . Video for Operating Room Coordination: Will the Staff Accept It?. *Anesthesiology: 101: A1389. 2004*

D. Technology evaluation.
We conducted evaluation studies of the technology deployed. The primary focus was on user acceptance and usage patterns. The focus was chosen because the current science of operating room management has concluded that improvement of decision making on the day of surgery will lead to improvement in intangible outcomes, such as situation awareness, and will unlikely lead to improvement in operating room throughput (e.g., volumes and economic returns). Our work was reported in the following publication.

9. Xiao Y, Dexter F, Hu FP, Dutton R. Usage of Distributed Displays of Operating Room Video when Real-Time Occupancy Status was Available . Anesthesia and Analgesia 2008; 106(2):554-560. 2008

10. Kim Y-J, Xiao Y, Hu P, Dutton RP. Staff Acceptance of Video Monitoring for Coordination: A Video System to Support Perioperative Situation Awareness. *Journal of Clinical Nursing (accepted). 2007*

The project team has worked on the use of advanced video technology to support coordination in operating rooms. We developed models for decision support systems for operating room management. We developed technology, primarily based on algorithms of video processing and biosignal processing, to display status of operating rooms.

In conjunction with technology development, we conducted observational and survey studies of operating room management. We conducted evaluation studies of the technology deployed. The primary focus was on user acceptance and usage patterns. The focus was chosen because the current science of operating room management has concluded that improvement of decision making on the day of surgery will lead to improvement in intangible outcomes, such as situation awareness, and will unlikely lead to improvement in operating room throughput (e.g., volumes and economic returns).

Informatics subgroup 5. Improving Perioperative Communications (IPC)

Background:

In the UMMS OR the Cardiac Surgery Service utilizes a common communications point (a “cardiac phone line”) that in a sense is used to acquire information and provide that information to any team member who calls the line to acquire information. The cardiac phone line has been scripted and is actively in use through a voice mail system. It can only be altered by dedicated personnel with password capability. The script involves the following standardized information: Identification of individual providing information, the Date of surgery, the Total number of cases, and OR location, patient name, case

order, medical record number, age, surgeon, anesthesiologist and procedure. Evening schedule updates have been made possible through a second phone line option.

After some effort, we can now move to track updates on the phone line and correlate these updates with OR start delays. Thus, we refined the IPC question to Does more accurate information as evidenced by updates on the phone line, ie improved communication, result in fewer problems in the morning with cardiac surgical cases starting on time- are instruments better prepared for the procedure, are operating rooms better equipped for the appropriate case, are the correct pick lists utilized for the correct surgeon, is there less of a transport delay because the patient's hospital location has been identified? The question contains reference to some of the delay codes that are currently utilized by the Operating room tracking system and reported for glitch analysis.

With the assistance of the communications personnel, we reconfigured the cardiac phone line so that we can actually track the phone calls made to the phone line. This enabled us to: Determine key personnel who are utilizing the phone line, Determine groups of personnel utilizing the phone line (i.e. nursing, anesthesia, perfusion), Determine which groups are not utilizing phone line information (i.e. anesthesia techs), Determine whether there is a time variable; is there a better time to call for updates? Should updates be made at predetermined times or should they be more dynamic?

We hypothesized that information gained from increased communication improves OR efficiency. If this is the case we can then move to see if more real-time enabling technologies might be deployed to other services within the UM ORs and perhaps other ORs "everywhere".

During work on this project last year, the team sought to find an appropriate "question" with which to focus this effort. In particular, there was a need to tie a performance metric (perioperative workflow related) to the IPC task. Although some progress was made, this aspect of Innovations in the Surgical Environment was terminated and future efforts will be refocused. Funding will be sought from other agencies

B. Simulation

Simulation.1 The Maryland Virtual Patient

We present here a simplified description of the MVP simulation, interaction and tutoring system. A virtual patient instance is launched and starts its simulated life, with one or more diseases progressing. When the virtual patient develops a certain level of symptoms, it presents to the attending physician, the system's user. The user can carry out, in an order of his or her choice, a range of actions: interview the patient, order diagnostic tests, order treatments, and schedule the patient for follow-up visits. The patient can also automatically initiate follow-up visits if its symptoms reach a certain level before a scheduled follow-up. This patient-physician interaction can continue as long as the patient "lives."

As of the time of writing, the implemented MVP system includes a realization of all of the above functionalities, though a number of means of realization are temporary placeholders for more sophisticated solutions, currently under development. The most obvious of the temporary solutions is the use of menu-based patient-user interaction instead of natural language interaction. While this compromise is somewhat unnatural for our group, which has spent the past 20 years working on knowledge-based NLP, it has proved useful in permitting us to focus attention on the non-trivial core modeling and simulation issues that form the backbone of the MVP system.

MVP currently covers six esophageal diseases pertinent to clinical medicine: achalasia, gastroesophageal reflux disease (GERD), laryngopharyngeal extraesophageal reflux disease (LERD), LERD-GERD (a combination of LERD and GERD), scleroderma esophagus and Zenker's diverticulum.

At the beginning of a simulation session, the system presents the user with a virtual patient about whose diagnosis he initially has no knowledge. The user then attempts to manage the patient by conducting office interviews, ordering diagnostic tests and prescribing treatments.

Answers to user questions and results of tests are stored in the user's copy of the patient profile, represented as a patient chart. At the beginning of the session, the chart is empty and the user's cognitive model of the patient is generic – it is just a model of the generalized human. The process of diagnosis results in a gradual modification of the user's copy of the patient's profile so that in the case of successful diagnosis, it closely resembles the actual physiological model of the patient, at least, with respect to the properties relevant to the patient's complaint. A good analog to this process of gradual uncovering of the user profile is the game of Battleship, where the players gradually determine the positions of their opponent's ships on a grid.

At any point during the management of the patient, the user may prescribe treatments. In other words, the system allows the user not only to issue queries but also to intervene in the simulation, changing property values within the patient. Any single change can induce other changes – that is, the operation of an agent can at any time activate the operation of another agent.

Simulation: Utility

The MVP project can be viewed as just one of a number of applications in the area of intelligent clinical systems. The latter, in turn, can be viewed as one of the possible domains in which one can apply modeling teams of intelligent agents featuring a combination of physical system simulation and cognitive processing.

So, in the most general terms, our work can be viewed as devoted to creating working models of societies of artificial intelligent agents that share a simulated "world" of an application domain with humans in order to jointly perform cognitive tasks that have

until now been performed exclusively by humans. Sample applications of such models include:

- a team of medical professionals diagnosing and treating a patient (with humans playing the role of either a physician or a patient)
- a team of intelligence or business analysts collecting information, reasoning about it and generating analyses or recommendations (with humans playing the role of team leader)
- a team of engineers designing or operating a physical plant (with humans playing the role of team leader)
- a learning environment (where humans play the role of students).

As can be seen, this work is at the confluence of several lines of research – cognitive modeling, ontological engineering, reasoning systems, multi-agent systems, simulation and natural language processing.

During the period of performance, we have been working on the following issues:

1. We have continued to develop a computational model of the cognitive agent. We have tested the goal- and plan-based reasoning component and its interaction with the interoceptive and language perception modules and verbal, mental and physical action simulation modules.

2. We have spent much of the time preparing for the demonstration of the system at the program conference and at several meetings of the American College of Surgeons. In particular, we have developed a new demo interface.

3. We have continued to work on the natural language substrate of the system, concentrating on enhancements required for processing dialog (not expository text). As part of this module, we have implemented an enhanced microtheory of indirect speech acts.

4. We have continued working reference resolution algorithms (this is a very difficult task in and of itself).

5. We have continued work on the acquisition of ontology and lexicon knowledge.

6. Improvement of the DEKADE user interface has continued apace. New facilities for editing and viewing intermediate and final results of text analysis have been introduced and existing ones improved.

7. We have spent considerable time on improving the documentation of the project work. We have written and submitted for publication 5 papers describing aspects of our system.

During this reporting period, the research team continued to refine the cognitive simulation system by adding more clinical scenarios and challenges. The communication between patient and physician has reached a high level of realism and clinical utility.

An extensive summary of this project's work was presented at the annual meeting of the American College of Surgeons, at the DOD-sponsored workshop on psychometrics of simulation/games, and a similar DOD meeting in San Antonio, Texas.

We continue to discuss with representatives of the DOD Medical Departments the application of cognitive simulation training for far-forward care providers. As this project winds down**,** the investigators will seek sources of funding to attain the potential of the cognitive simulation system.

Simulation.2 Training for Surgical Excellence and Patient Safety

The development of the Maryland Advanced Simulation, Training, Research and Innovation center (MASTRI) opened the door to innovative research opportunities that enhance surgical training and improve patient safety. Within the existing scope of the current contract, several projects will be undertaken during the final year of the contract that conceive, develop and validate simulation-based training for proficiency in the performance of surgical tasks.

For the milestone pertaining to the exploration of the application of technologies to refine methods of medical instruction, the following activities took place:

- Online training system: we have developed offline resources for training laparoscopic cholesystectomy procedures involving the use of video vignettes. These resources are slated for implementation using an online learning system. We have identified a doctoral candidate in computer science to facilitate implementation of the system.
- Audience polling system: We have recently acquired a system for audience-response measurement. Our system for audience-response measurement is now integrated into the training of all residents for polling response to training and medical grand rounds. This system will also be used to facilitate and enhance our presentation at the annual meeting of the Society for Simulation in HealthCare.
- Simulation-based competency based training: We are currently refining and expanding our use of criteria-based training, which uses measures of performance to determine training sufficiency. We are currently refining the criteria for Virtual reality (VR) and physical-model training for basic laparoscopic skills.

For the milestone related to developing new models for simulation training:

- Arthroscopic simulation: Arthroscopic skills models continue to be refined. A new model for spinal disk herniation has been developed in the form of a prototype. Pilot testing of the model's functions has been carried out. Curriculum for the model is being developed.

- Ventral hernia: Provisional patent obtained. Prosecution of full patent is in process. Pilot validation trials of our model have been carried out by another university. The simulator is now in routine use as a teaching tool for fellows, residents, and industry representatives, and provides a cost-effective alternative to porcine model of ventral hernia repair. Validation trials are being designed.
- Suture-skills drill: A new physical model of tissue and pattern of visual targets marked upon the tissue was developed for a flexible curriculum of training suturing skills. We are in the process of refining models for developing the curriculum for drills to practice suturing skills.

For the milestone related to configuring the training site for OR, ICU, Emergency Department and Team Training scenarios:

New equipment and infrastructure were acquired during this reporting period. Specifically, additional simulation equipment to be used for a variety of procedural and skill-based instruction has been delivered. The Sim baby simulator has been obtained, a pediatric exam bed has been integrated into the simulation space, ultrasound equipment was obtained, allowing ultrasound-guided catheter placement training, curtains and storage have been installed, and new part-task trainers have been obtained.

- Significant progress has been made in the configuration of and use of OR B as a training site. Video and audio cabling and networking hardware has been installed and all communication systems are near completion.
- Hiring of a simulation educator/technician has brought us to near full operation of the OR B training site.
- Many new full and part-task trainers have allowed the beginning of several courses with a large number waiting in the wings. More than a dozen new courses for medical and surgical residents, nursing personnel and medical students have been introduced using this new training site.

For the development of collaborative ventures with academic institutions and government agencies, we are currently preparing extramural grant proposals on the topic of developing metrics for surgical training, specifically regarding the assessment of medical resident performance. Substantive collaboration is dependent on receipt of funding.

C. Smart Image

C.1 Smart Image: CT-guided Imaging

Having completed the entirety of the experimental and animal imaging work, our efforts remained focused on data processing and scientific reporting during the current year. The following were significant notable outcomes.

1. We made an oral presentation on our work on Live AR at the SAGES conference help in Phoenix, AZ in April 2009. Subsequently, an in-depth manuscript on the same topic was submitted to Surgical Endoscopy, the official journal of SAGES, for possible

publication. **The submitted manuscript is placed in the Appendix.** This reporting period included work on refining and producing results, especially Live AR movie clips, for the conference presentation and the manuscript.

2. We also presented a poster at the Computer-Assisted Radiology and Surgery (CARS) conference in Berlin, Germany in June 2009. This presentation explored the specific topic of using image registration for continuous volumetric CT-guided interventions. **A copy of the abstract is presented in the Appendix.** A manuscript will follow this presentation.

3. We continued to work on low-dose CT reconstruction, one of the originally proposed technical objectives. We worked with Philips, the manufacturer of our CT scanner, on data preprocessing issues that now enable us to reconstruct images with a consistent orientation and thereby allow head-to-head comparison of reconstructed images when x-ray dose is varied. A manuscript summarizing the work will be prepared and submitted in the upcoming year.

C.2. Smart Image: Image Pipeline

The work we have completed in the past year is summarized in a number of peer-reviewed publications and has been shared in several presentations. These are discussed in the context of our overall goals – to develop visualization requirements, principles, and frameworks, as well as solutions to specific computational challenges, which will permit useful and usable augmentation of the laparoscopic image. This augmentation assumes input from other modalities, including surgeons' annotations, as well as pre-operative and intra-operative CT and other imaging techniques. The full papers are in the appendix.

Visualization Framework:

We have described the overall visualization framework for the Smart Image project, including both the computational and usability components, in a paper submitted to *Surgical Innovations*:

1) Yang, R., Carswell, C.M., Wang, X., Zhang, Q., Han, Q., Lio, C., and Seales, B. Mapping the Way to a Dual Display Framework for Laparoscopic Surgery.

Abstract:

Many performance and workload problems associated with the use of traditional laparoscopic displays are the result of spatial disorientation. This premise has guided our development of a dual display framework for computer-augmented surgical displays, allowing us to take guidance from research on how to design successful navigation aids (navaids) for large-scale environments. Our dual-display combines the traditional scope (forward track) view with a computationally-generated global 3D (map) view. The latter provides a wider field of view, explicit cues to depth and scale, and a way to view interior

and exterior surfaces of target anatomy from different approach angles. One way to implement such a 3D view is to extract images of surface textures from a laparoscopy video sequence and then map the texture onto pre-built 3D objects, for example surface models derived from MR/CT. We describe an algorithm that takes advantage of the fact that nearby frames within a video sequence usually contain enough coherence to allow 2D-2D registration, a much better understood problem than 2D-3D registration. Our texturing process can be bootstrapped by an initial 2D-3D manual-assisted registration of the first video frame followed by mostly-automatic texturing of subsequence frames. Initial research on the validity of our technical approach indicates that it improves registration performance compared to a standard registration technique that relies on camera tracking. Ongoing technical and usability evaluations of the system are being conducted in order to ensure system functionality.

Front end assessments for requirements and acceptability are described in a peer-reviewed proceedings paper presented at the 2009 Human Factors and Ergonomics Society meeting.

2) Lio, C.H., Carswell, C.M., Han, Q., Park, A., Strup, S., Selaes, W.B., Clarke, D., Lee, G., and Hoskins, J. (2009). Using Formal Qualitative Methods to Guide Early Development
of an Augmented Reality Display System for Surgery. Proceedings of the Human Factors and Ergonomics Society 53rd Annual Meeting. Santa Monica, CA: HFES.
Abstract:

Nine laparoscopic surgical experts (2 residents, 4 fellows, and 3 surgeons) underwent semi-structured interview questions to evaluate the concept of a "dual-view" display for laparoscopic surgery. The 30-40 minute audio-recorded interviews were transcribed, submitted to an open source qualitative program for classification and categorizing, and were condensed for the iterative processes of analysis and interpretation. Findings revealed that despite the relatively brief interview sessions and limited number of surgical experts available, the experts provided sufficient insights and suggestions to guide further development of prototypes. This means that the use of semi-structured interviews as an expert knowledge elicitation technique may be suitable for assessing the development of augmented reality display systems for surgical and training applications, and it may have promise for the development of augmented and
virtual environments more genially.

Computational Challenges:

The past year also saw the publication of a peer-reviewed journal article summarizing the procedure we have developed for registering a series of video images from the laparoscope to prebuilt surface models without using camera tracking.

3) Want, X., Zhang, Q., Han, Q., Yang, R., Carswell, M., Seales, B., and Sutton, E. (2009) Endoscopic video texture mapping on pre-built 3D anatomical objects without camera tracking. IEEE Transactions on Medication Imaging, 7(7), 1-12.

Abstract:

Traditional minimally invasive surgeries use a view port provided by an endoscope or laparoscope. We argue that a useful addition to typical endoscopic imagery would be a global 3D view providing a wider field of view with explicit depth information for both the exterior and interior of target anatomy. One technical challenge of implementing such a view is
finding efficient and accurate means of registering texture images from the laparoscope on pre-built 3D surface models of target anatomy derived from magnetic resonance (MR) or computed
tomography (CT) images. This paper presents a novel method for addressing this challenge that differs from previous approaches, which depend on tracking the position of the laparoscope. We
take advantage of the fact that neighboring frames within a video sequence usually contain enough coherence to allow a 2D-2D registration, which is a much more tractable problem.
The texturing process can be bootstrapped by an initial 2D-3D user-assisted registration of the first video frame followed by mostly-automatic texturing of subsequent frames. We perform
experiments on phantom and real data, validate the algorithm against the ground truth, and compare it with the traditional tracking method by simulations. Experiments show that our
method improves registration performance compared to the traditional tracking approach.

We also published a peer-reviewed proceedings paper on a method for acquiring and reconstructing 3D surface models based on light fall-off between the camera and organ surface.

4) Liao, M., Wang, L., Yang, R., and Gong, M. Real-time light fall-off stereo. (2008). International Conference on Image Processing (ICIP).

Abstract:

We present a real-time depth recovery system using Light Fall-off Stereo (LFS). Our system contains two co-axial point light sources (LEDs) synchronized with a video camera. The
video camera captures the scene under these two LEDs in complementary states(e.g., one on, one off). Based on the inverse square law for light intensity, the depth can be directly solved using the pixel ratio from two consecutive frames. We demonstrate the effectiveness of our approach with a number of real world scenes. Quantitative evaluation shows that our
system compares favorably to other commercial real-time 3D range sensors, particularly in textured areas. We believe our system offers a low-cost high-resolution alternative for depth

sensing under controlled lighting.

Yet another peer-reviewed proceedings paper was recently presented at MICAI (Medical Image Computing & Computer Assisted Intervention) and dealt with the methods to model the intra-object deformations with using a small number of parameters that can be applied to new target objects. This allows for better registration of pre-built 3D shape models of target organs to their corresponding laparoscopic video sequence.

5) Han, Q. Strup, S., Carswell, C.M., Clarke, D., Seales, W.B. (2009). Model Completion via Deformation Cloning Based on an Explicit Global Deformation Model. 12th International Conference on Medical Image Computing & Computer Assisted Intervention (MICCAI)(1) 2009: 1067-1074.

Abstract:

Our main focus is the registration and visualization of a pre-built 3D model from preoperative images to the camera view of a minimally invasive surgery (MIS). Accurate estimation of soft-tissue deformations is key to the success of such a registration. This paper proposes an explicit statistical model to represent global non-rigid deformations. The deformation model built from a reference object is cloned to a target object to guide the registration of the pre-built model, which completes the deformed target object when only a part of the object is naturally visible in the camera view. The registered target model is then used to estimate deformations of its substructures. Our method requires a small number of landmarks to be reconstructed from the camera view. The registration is driven by a small set of parameters, making it suitable for real-time visualization.

Continuing Work:

We shipped the completed dual display simulation (interactive prototype for usability testing) to UMMC. This allows for the precise assessment of the presumed advantages of our dual display framework for navigation and the development of adequate spatial situation models. It is our hope that the framework will form the basis for continued collaboration and development of user-centered visualization systems for minimally invasive surgery.

Key Research Accomplishments

A. Informatics

Informatics subgroup 1. Perioperative Scheduling Study

Major Accomplishments achieved during this period of performance include the development of a mathematical congestion evaluation model for evaluating congestion in post-operative units, including ICUs, IMCs, and floor units. This model requires data about post-operative destinations and length-of-stay distributions for different types of surgeries. We analyzed data about cardiac surgeries from two years and have analyzed UMMC financial records for all of the surgical cases for a year.

Informatics subgroup 2. Operating Room Glitch Analysis

A tactical dashboard was developed in conjunction with the strategic dashboard and has been deployed to an internally hosted server. The tactical dashboard is being used within the perioperative environment to evaluate OR utilization, scheduling workflow, and case data accuracy. Data are being validated at the case level and new processes for data entry are being designed to ensure the accuracy of the metrics within the strategic dashboard.

Informatics subgroup 3. Context Aware Surgical Training (CAST)

A prototype CAST system was emplaced in the MASTRI system for assessment. Work was done to design a system of evaluation of the system in terms of improvements in learning outcomes due to self-feedback, improvements in learning outcomes due to instructor feedback and synchronous versus asynchronous feedback. We demonstrated the system to a set of resident volunteers for feedback in a form of Beta-test of the system. We set up hardware and software to include the VR Simulator as part of the CAST system deployment. We got usability feedback and fixed bugs.

Informatics subgroup 3. Video Summarization

We completed an initial analysis of this problem. We compared more than 50 image features with a distance metric to identify the critical view of a laparoscopic cholecystectomy. We experimented with roughly 50 different images features and several distance metrics. Our initial results showed a 72% sensitivity and 72% specificity. An abstract was submitted to the American Medical Informatics Association (AMIA) Fall Symposium.

Informatics subgroup 4. Operating Room Clutter (ORC)

During this period of performance, we published 8 full-length peer reviewed journal articles, 2 full-length peer reviewed proceeding articles, and 8 conference abstracts.

B. Simulation (Virtual Patient)

n this final year of the project, our team has delivered additional versions of the Maryland Virtual Patient Environment. The realism of the simulation has been enhanced by including coverage of "unexpected" interventions; allowing discontinued treatments; allowing new diseases to develop due to side effects of treatments. The user interface has been redesigned. A new agent-based architecture has been developed to support enhanced cognitive capabilities of the virtual patient and the intelligent tutor, including language capabilities. In the area of language processing, a dialog processing model was developed. Work has continued on improving the language understanding capabilities, centrally including treatment of referring expressions. Enhancement of static knowledge resources, the ontology and the lexicon, has been ongoing. Work on extending the coverage of diseases has been ongoing: a further improvement of the model of GERD is under way, as is the modeling of cardiovascular diseases. A totally reworked system version, with dialog support, was released in June 2008. Work has also been ongoing on improving and extending the set of development tools – the DEKADE demonstration, evaluation and knowledge acquisition environment supporting natural language work has been revamped; the interface for creating instances of virtual patients has also been

enhanced; a web-based environment for supporting internal documentation has been installed.

B. Simulation (Training for Surgical Excellence)

For the milestone related to configuring the training site for OR, ICU, Emergency Department and Team Training scenarios, new equipment and infrastructure were acquired during this reporting period. Specifically, additional simulation equipment to be used for a variety of procedural and skill-based instruction has been delivered. The Sim baby simulator has been obtained, a pediatric exam bed has been integrated into the simulation space, ultrasound equipment was obtained, allowing ultrasound-guided catheter placement training, curtains and storage have been installed, and new part-task trainers have been obtained. Significant progress has been made in the configuration of and use of OR B as a training site. Video and audio cabling and networking hardware has been installed and all communication systems are near completion. Hiring of a simulation educator/technician has brought us to near full operation of the OR B training site. Many new full and part-task trainers have allowed the beginning of several courses with a large number waiting in the wings. More than a dozen new courses for medical and surgical residents, nursing personnel and medical students have been introduced using this new training site.

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input from other modalities, including surgeons' annotations, as well as pre-operative and intra-operative CT and other imaging techniques.

Reportable Outcomes

We advanced the body of knowledge pertaining to informatics, smart image, simulation and human factors as these relate to surgical procedures, the perioperative environment and the training of surgery. We published more than forty manuscripts, hosted national and international meetings related to innovation in the surgical environment, and incorporated technical advances into patient care in a large academic medical center. We influenced significantly the training of more than three hundred fellows and residents, hundreds of staff and care providers and numerous medical students.

Perhaps our most important accomplishment has been the identification of a new of basic surgical sciences. These include computer and physical sciences, informatics, smart imaging, simulation and ergonomics and human factors that underpin surgical training. This event is a landmark of sorts, as it has changed forever the course of surgical education. Lessons learned from this research effort are being applied in training programs throughout the country and internationally.

Conclusion

This report began with the recognition that an extraordinary evolution in surgical care has occurred caused by rapid advances in technology and creative approaches to medicine. The increased speed and power of computer applications, the rise of visualization technologies related to imaging and image guidance, improvement in simulation-based technologies (tissue properties, tool-tissue interaction, graphics, haptics, etc) have interacted to advance the practice of surgery. However, the medical profession lags behind other applications of information systems. The research program reported here has proceeded under the mantle of "Operating Room of the Future". As a natural occurrence in the outcome of lessons learned in medicine, we are replacing that theme with the more appropriate "Innovations in the Surgical Environment."

This research program has consisted of three major pillars; OR informatics, simulation, and smart image. This year, we incorporated the research focus areas of physical and cognitive ergonomics and human factors into the informatics pillar. A summary description of the entire research portfolio was included in the appendix.
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The purpose of the OR informatics program is to develop, test, and deploy technologies to collect real-time data about key tasks and process elements in clinical operating rooms. We have established testbeds of activities in both simulated and operational environments. We are currently performing tests of the hardware, refining software, and applying lessons learned to hospital operational functions. The objective of Simulation research is to create a system where a user can interact with a virtual human model in cognitive simulation and have the virtual human respond appropriately to user queries

and interventions in clinical situations, with a focus on cognitive decision making and judgment. We have made significant strides toward realizing these goals. The MVP simulation functions well for esophageal disorders, and is continuing to expand the repertoire of diseases that are in the simulation model.

The objective of smart image is use real-time 3D ultrasonography and 40-slice highframe-rate computed tomography (CT) for intraoperative imaging to volume rendered anatomy from the perspective of the endoscope. We are combining CT and Ultrasound to overlay image and data to enhance the performance of surgeons-in-training. We have carried out animate model testing of the image registration with great success. We continue to refine and expand our capability through hardware and software refinement.

In the future, OR workspace layout would be optimized through ergonomic data and human factors analysis, and this optimization would lead to the establishment of "best practices" for an array of surgical operations. Proper layout would reduce risks of infection, speed operations, and reduce fatigue of surgeons and staff, all elements that could contribute to a reduction in AEs and improved patient safety.

The year ahead is full of promise for refinements in the use of informatics to support safe and efficient operating room procedures, the use of simulation to improve and accelerate the training of competent surgeons, and the blending of imaging capabilities to provide clearer and safer interactions between patient and surgeon.

As stated earlier in this report, the current contract, W81XWH-06-2-0057, has been tied to a prior and topically related contract, DAMD-17-03-2-0001. The prior contract closed in February of 2009; the current one was scheduled to close in October of 2009; this contract was granted a no-cost extension until October, 2010. Some projects contained in the Informatics pillar, OGA, ORC and IPC, have been completed. The WORQ project will continue under the current contract as will the CAST project that has been reshaped into Video Summarization. Simulation for Training and the ergonomics/human factors work will continue through the period of no-cost extension.

These changes represent the maturing of a research endeavor over the course of six years, an endeavor which opened the door to a new set of basic surgical sciences. The Innovations in the Surgical Environment conference planned for the spring of 2010 will summarize the entirety of the research effort and point the direction to future innovative approaches to advance surgical technology in behalf of patient safety.

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APPENDICES

A. Computer Input Devices: Neutral Party or Source of Significant Error in Manual Lesion Segmentation? In **Journal of Digital Imaging**, James Y. Chen, F. Jacob Seagull, Paul Nagy, Paras Lakhani, Elias R. Melhem, Eliot L. Siegel, and Nabile M. Safdar.

Journal of Digital Imaging

Computer Input Devices: Neutral Party or Source of Significant Error in Manual Lesion Segmentation?

James Y. Chen,[1,2,3] F. Jacob Seagull,[2] Paul Nagy,[2] Paras Lakhani,[1,2] Elias R. Melhem,[1] Eliot L. Siegel,[2,4] and Nabile M. Safdar[2]

Lesion segmentation involves outlining the contour of an abnormality on an image to distinguish boundaries between normal and abnormal tissue and is essential to track malignant and benign disease in medical imaging for clinical, research, and treatment purposes. A laser optical mouse and a graphics tablet were used by radiologists to segment 12 simulated reference lesions per subject in two groups (one group comprised three lesion morphologies in two sizes, one for each input device for each device two sets of six, composed of three morphologies in two sizes each). Time for segmentation was recorded. Subjects completed an opinion survey following segmentation. Error in contour segmentation was calculated using root mean square error. Error in area of segmentation was calculated compared to the reference lesion. 11 radiologists segmented a total of 132 simulated lesions. Overall error in contour segmentation was less with the graphics tablet than with the mouse ($P<0.0001$). Error in area of segmentation was not significantly different between the tablet and the mouse ($P = 0.62$). Time for segmentation was less with the tablet than the mouse ($P = 0.011$). All subjects preferred the graphics tablet for future segmentation ($P = 0.011$) and felt subjectively that the tablet was faster, easier, and more accurate ($P = 0.0005$). For purposes in which accuracy in contour of lesion segmentation is of the greater importance, the graphics tablet is superior to the mouse in accuracy with a small speed benefit. For purposes in which accuracy of area of lesion segmentation is of greater importance, the graphics tablet and mouse are equally accurate.

KEY WORDS: Image segmentation, user-computer interface, computer assisted detection, computer hardware, data collection, human computer interaction, evaluation research, segmentation

INTRODUCTION

Lesion segmentation involves outlining the contour of an abnormality on an image to distinguish boundaries between normal and abnormal tissue. Segmentation of lesion volume (or area on 2D images slices) is essential to track malignant and benign disease in medical imaging for clinical, research, and treatment purposes.

Clinically, large trials such as the ACRIN National Lung Screening Trial as well as individual clinical cases currently rely on accurate and repeatable methods of lesion measurement and segmentation.[1–5] Automated tumor segmentation for radiation therapy can improve treatment planning accuracy[6] and highly localized radiotherapies, such as proton beam,[7] require accurate pre-treatment targeting.[8,9]

For research, segmentation can be used for objective comparison of new imaging sequences and modalities or for the creation of automated segmentation tools.[10–13] The validation of automated segmentation tools commonly relies on testing for lesion contour and size against manual segmentation.[14–19] Manual lesion segmentation, however, may vary in accuracy, depending on the input method used for measurement. To our

[1]*From the University of Pennsylvania, Philadelphia, USA.*
[2]*From the University of Maryland, College Park, USA.*
[3]*From the San Diego Veterans Administration Hospital, University of California San Diego, 3350 La Jolla Village Dr, San Diego, CA, 92161, USA.*
[4]*From the Baltimore Veterans Administration Hospital, Baltimore, USA.*
Correspondence to: James Y. Chen, San Diego Veterans Administration Hospital, University of California San Diego, 3350 La Jolla Village Dr, San Diego, CA, 92161, USA; e-mail: James_Chen@alumni.brown.edu

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knowledge, nearly all clinical and research users use the mouse as the input device for manual lesion segmentation.

The QWERTY keyboard and mouse are the de facto standard configuration in computer input devices. Although these work well for standard user interface interactions, many graphic designers have chosen to replace or augment these devices with graphics tablets that more closely mimic conventional pen and paper. Applications that require manual lesion segmentation bear similarities to the tasks of graphic designers, chiefly a need for finer motor control. Most people performing segmentation, however, still rely mainly on the mouse interface. The mouse interface can be variably accurate and used with either finer finger and wrist movements or larger arm and wrist movements; whereas, the accuracy of pen strokes is typically limited to fine movements such as wrist flexion.

To our knowledge, at the time of the writing of this manuscript, there has been a single published medical study comparing the accuracy of the computer mouse with alternative input devices including the graphics tablet and touch-sensitive screen.[20]

We hypothesize that the pen-and-tablet interface should be empirically and subjectively at least as accurate, easy, and fast as an optical mouse for lesion segmentation in regards to both lesion contour and size.

MATERIALS AND METHODS

This is an IRB-approved prospective study comparing two different computer input devices for manual segmentation of simulated lesions, including a post-experiment survey of all participants.

Simulated reference lesions were created and then combined into one set of two groups of six images. One group comprised of three lesion morphologies in two sizes, one for each input device (Fig. 1). Lesion contours were created to simulate clinical lesions, including ovoid, lobulated, and spiculated forms. To account for differences in lesion size/zooming, three lesion shapes were resized 50% in each dimension using bicubic interpolation to create a second group of three smaller size lesions. Each image contained only a single lesion with high-contrast, black-on-white backgrounds, and hard edges to minimize the cognitive task and time required to identify the lesion and its borders.

A wireless, 800 dpi, laser mouse (Logitech International S.A.; Switzerland) using the default software driver (Microsoft Corporation, version 5.1.2600.5512) was set to default movement parameters including variable gain/acceleration. The batteries were used for less than 1 week during the experiment to minimize performance degradation from battery exhaustion, and the same non-reflective mouse surface was used for all subjects. The graphics tablet (Wacom Corporation; Japan) was also set to default parameters within

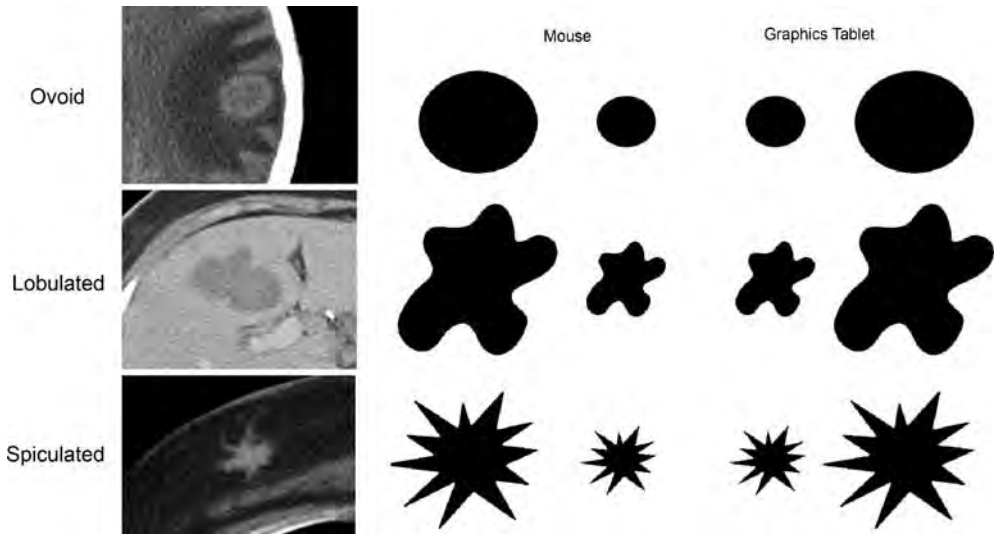

Fig 1. Three lesion shapes (*left*) were used as templates to create high-contrast, hard-edged images in two sizes each. Study participants segmented one set of six images with the mouse and the other set of six images with the graphics tablet.

the driver software (Wacom Corporation, version 6.00-5) and matched the aspect ratio of the viewing screen. Subjects were encouraged to position both devices and display for their comfort.

Radiologists performed manual lesion segmentation with each input device for each group of six images (12 lesion segmentations per subject) using commercially available image editing software (Adobe Systems, USA). Simulated lesions and segmentation device order were randomized for each subject. Participants were allowed a single image on which to practice segmentation up to two times with each input device prior to segmenting each experimental set. Segmentation time was recorded manually for each individual lesion by a single observer throughout the study.

To evaluate error in contour of segmented lesions, undersegmented and oversegmented areas were combined to assess the mis-sampled area. Undersegmented areas were defined as areas of reference lesion that was not included in manual segmentation (false exclusion). Oversegmented areas were defined as areas of segmented lesion that did not correlate to the reference lesion (false inclusion). The segmented lesions were subtracted from the reference lesion to obtain areas of undersegmentation; the reference lesion was then subtracted from the segmented lesion to obtain the area of oversegmentation. The root mean square error was then calculated from the undersegmented and oversegmented areas. Statistical differences were compared with a Wilcoxon test.

To evaluate error in area of segmented lesions, total area of segmentation was recorded for each lesion and the difference in area from the reference lesion was calculated. These differences were compared with a Wilcoxon test.

After segmentation of both lesion sets, each individual completed a force-choice survey between the graphics tablet and mouse for perceived ease, speed, and accuracy of segmentation; and device preference for segmenting lesions in the future. Statistical differences in preferences were compared with a binomial test. Subject demographics were recorded during the survey including number of years of experience with a mouse or tablet.

RESULTS

Eleven radiologists (nine male, two female) participated in the study, segmenting a total of 132 lesions.

Average lesion area was 16,041 pixels with large lesions averaging 22,203 pixels, and small lesions averaging 5,508 pixels. Ovoid lesions averaged 12,562 pixels, lobulated lesions 18,569 pixels, and spiculated lesions 10,437 pixels.

Contour segmentation with the tablet was more accurate than with a mouse (Table 1) with average RMS error of 690 (standard deviation of 530, overall RMS of 4.3% of average lesion area) versus 992 (standard deviation of 1,033, overall RMS of 6.2% of average lesion area, an increase of 44% in error; $P<0.0001$). For the large lesions, the tablet demonstrated significantly less error (RMS error of 1,003, standard deviation of 617, overall RMS of 4.5% of large lesion area) compared to the mouse (RMS error of 1,489, standard deviation of 1,288, overall RMS of 6.7% of average large lesion area, corresponding to a 48% increase in error; $P<0.0001$). For small lesions, the tablet also demonstrated significantly less error (RMS error of 377, standard deviation of 246, overall RMS of 6.8% of small lesion area) compared to the mouse (RMS error of 496, standard deviation of 390, overall RMS of 9.0% of small lesion area, corresponding to a 32% increase in error; $P=0.0121$). Of the 11 partic-

Table 1. Root Mean Square Error in Contour Error as a Percent of Reference Lesion Area

Contour segmentation error between graphics tablet and mouse

Lesion set	Tablet	Mouse	Increase from tablet	*P*
All lesions	4.3%	6.2%	44%	<0.0001
Large lesions	4.5%	6.7%	48%	<0.0001
Small lesions	6.8%	9.0%	32%	0.0121
Ovoid lesions	2.9%	4.6%	59%	0.0008
Lobulated lesions	3.8%	5.1%	33%	0.0127
Spiculated lesions	9.3%	14%	46%	0.0156

There is significantly greater contour error with a mouse across all lesions and lesion subgroups

ipants, ten (91%) were more accurate with the tablet compared to one (9%) with the mouse.

When lesions were subgrouped into ovoid, lobulated, and spiculated morphologies, the tablet again demonstrated less contour error than the mouse, except with the lobulated lesions. For lobulated lesions, the tablet demonstrated significantly less error (P=0.0127). Tablet error (RMS of 714, standard deviation of 498, overall RMS 3.8% of lobulated lesion area) compared to the mouse (RMS of 950, standard deviation of 898, overall RMS of 5.1% of lobulated lesion area, corresponding to 33% increase in error of 33%). With ovoid lesions, the tablet demonstrated significantly less error (RMS of 364, standard deviation of 294, overall RMS 2.9% of ovoid lesion area) compared to the mouse (RMS of 580, standard deviation of 574, overall RMS 4.6% of ovoid lesion area, corresponding to a 59% increase in error; P=0.0008). With spiculated lesions, the tablet demonstrated significantly less error (RMS of 975, standard deviation of 682, overall 9.3% of spiculated lesion area) compared to the mouse (RMS of 1,424, standard deviation of 1,431, overall 13.6% of spiculated lesion area corresponding to a 46% increase in error; P=0.0156).

Error in pixel area of segmentation with the tablet and mouse was not significantly different (Table 2). Across all lesions, the tablet demonstrated a mean error in area of 678 pixels (4.9% of lesion area and standard deviation of 920 pixels) compared to 617 pixels (4.5% of lesion area and a standard deviation of 1,119 pixels) for the mouse (P=0.6194). For large lesions, the tablet demonstrated a mean error in area of 1,052 pixels (4.7% of lesion area and standard deviation of 1,114 pixels) compared to 954 pixels for the mouse (4.3% of lesion area and standard deviation of 1,402 pixels; P=0.4658). For small lesions, the tablet demonstrated a mean error in area of 318 pixels (5.8% of lesion area and standard deviation of 458 pixels) compared to 322 pixels for the mouse (5.8% of lesion area and standard deviation of 628 pixels; P=0.8442). For ovoid lesions, the tablet demonstrated a mean error in area of 364 pixels (2.9% of lesion area and standard deviation of 555 pixels), compared to −17 pixels for the mouse (−0.1% of lesion area and standard deviation of 998 pixels; P=0.2479). For lobulated lesions, the tablet demonstrated a mean error in area of 362 pixels (1.9% of lesion area and standard deviation of 875 pixels) compared to 499 pixels for the mouse (2.7% of lesion area and standard deviation of 593 pixels; P=0.8486). For spiculated lesions, the tablet demonstrated a mean error in area of 1,309 pixels (12.5% of lesion area and standard deviation of 958 pixels) compared to 1,421 pixels for the mouse (13.6% of lesion area and standard deviation of 1,184 pixels; P=0.8382). Of the 11 participants, seven were more overall more accurate with the tablet (64%) than with the four with the mouse (36%).

Table 2. Pixel Area Error as a Percent of Reference Lesion Pixel Area

Pixel area segmentation error between graphics tablet and mouse			
Lesion set	Tablet	Mouse	*P*
All lesions	4.9%	4.5%	0.619
Large	4.7%	4.3%	0.466
Small	5.8%	5.8%	0.844
Ovoid	2.9%	−0.1%	0.248
Lobulated	1.9%	2.7%	0.849
Spiculated	13%	14%	0.838

There is no significant difference in pixel area error between the graphics tablet and mouse

Overall lesion segmentation time was statistically significantly less with the tablet, averaging 27 s versus 29 s with the mouse (P=0.031, R^2= 0.96). For the small lesions, the tablet (23 s) was significantly faster than the mouse (25 s; P= 0.011). There was no significant difference between the tablet and mouse when other subsets were analyzed. For the large lesions, there was no significant difference between the tablet (32 s) and mouse (34 s; P=0.24). There was no difference in segmentation time for ovoid lesions between the tablet (15 s) and mouse (16 S; P=0.41), for lobulated lesions between the tablet (24 s) and mouse (27 s; P=0.22), or for spiculated lesions (42 s) versus (45 s) (P=0.13).

All radiologists reported more experience using a mouse than a tablet, with 100% having >5 years of mouse experience. Only three subjects (27%) had previously used a graphics tablet, two (18%) reported up to 1 year of experience, and one (9%) reported 3–5 years of experience.

Nine (82%) reported the perception that segmentation with tablet was faster, while one (9%) perceived the mouse to be faster, and one (9%) abstained from the question (P=0.011).

All (100%) participants reported segmentation with a mouse to be more difficult as well as less accurate. All (100%) participants also reported a

preference for using a graphic tablet in the future when segmenting lesions (P=0.0005).

DISCUSSION

A significant decrease in contour error was seen when manually segmenting lesions with a graphics tablet compared with the same task performed with a mouse, but no significant difference in pixel area error. Despite a general lack of experience with a graphics tablet, there was a small, but statistically significant decrease in time to segment lesions between the graphics tablet and mouse. All operators reported the graphics tablet to be subjectively more accurate and easier, and all preferred the tablet for future task performance. This suggests that with the same amount or decreased time expenditure, lesions can be segmented more accurately in contour or equally accurately in area with less effort than with a mouse, a finding that could have significant implications for research or clinical work involving large numbers of lesions. These results mirror findings in the computing literature that the tablet input device is more accurate for precision movements.[21,22]

While the contour segmentation error as a percentage of total lesion area was relatively small, ranging from an average of 5–14% for the mouse and 2.9–9% for the tablet, this was for a single image in 2D space. Actual pathology occurs in 3D space and accurate assessment of lesion volume would require segmenting a stack of 2D images and adding the areas to calculate 3D volume. Even these small errors accumulated over a stack of images can potentially result in significant cumulative error. In clinical trials where relatively small differences are expected of treatment efficacy, even these small amounts of error can have potentially large effects on study data and results. For highly targeted radiotherapeutic treatments, small errors in targeting can result in under-treatment of a lesion or damage to non-pathologic structures adjacent to the intended target.

When error in the total area of segmentation was compared, there was no statistically significant difference between the graphics tablet and the mouse. For purposes in which total lesion size is the subject of interest over lesion contour, such as in clinical evaluation of lesion size for treatment response or dosing of medication, the mouse and tablet can be considered equivalent.

The perceived increased ease of lesion segmentation may magnify differences between the mouse and graphics tablet when large volumes of lesions are segmented within and across patients. One set of investigators have found that a pen tablet system creates less overall muscular load than a mouse,[23] while another found improved productivity in general cursor control.[24] Operator fatigue and frustration with the input method during segmentation can lead to less accurate segmentation when the task is performed repeatedly. If segmentation with the tablet is truly easier, the graphics tablet could potentially decrease the amount of and effects of fatigue. This could result in creating more accurate datasets with large numbers of segmented lesions against which to evaluate automated methods of segmentation and new imaging sequences or modalities as they are developed.

We speculate that additional experience with the tablet beyond that held by the participants in this study might increase the speed of lesion segmentation but only minimally affect accuracy—an area that remains for future evaluation.

LIMITATIONS

Manual timing of lesion segmentation time introduces the possibility that the differences in segmentation time were at least partially, if not, wholly related to variability in relying on a human observer. As a single human observer performed timing measurements for all data points, variability was limited to that single observer instead of across multiple observers. Another study found that the tablet is faster than the mouse for accurate clinical contouring.[25]

The study design was not conducive to a meaningful analysis of intra-observer variability, as no participant performed the same task more than once. Any analysis of intraobserver variability would therefore be confounded by additional factors, such as size and/or shape of the segmented lesion, and the device used. This design was chosen to limit the total time required by the participants.

Study participants were not allowed to correct their lesion segmentations post hoc. In clinical use, radiologists have the opportunity to correct their

lesions segmentations regardless of the input device used, but the frequency and total amount of correction are not known. An input device which introduces greater error would also increase the time and labor burden of correcting the segmentation potentially decreasing the incentive for error correction. This could lead to the creation of segmented data sets with greater total error.

Our generalizability to true clinical images and lesion segmentation is currently unknown, but is a potential area for future investigation. Lesions seen in clinical imaging studies can be less conspicuous and may have less well-defined margins. This can complicate the cognitive task of defining a lesion's presence and borders, but we expect that this would affect the use of both the graphics tablet and mouse equally.

Two of our subjects expressed a dislike for the specific mouse and mouse-surface used in this study. The mouse and surface chosen, however, were popularly available, commercial products with conventional designs, which are expected to be similar to the default devices provided for clinical use. It is unknown whether this is related to the specific devices or related to a preference of different driver settings. In this study, default settings were chosen, as these were felt to be the most commonly used in clinical workstations. The effect of the specific mouse, mouse surface, and driver settings may be a topic for future investigation.

CONCLUSION

The choice of input device for manual lesion segmentation was found to significantly affect accuracy of segmentation of lesion contour, but not total lesion size. These findings suggest that for specific purposes in which lesion contour is of greater importance, such as in comparing different imaging sequences and modalities or for targeting highly selective radiotherapy, there is significantly greater error with a mouse than with a graphics tablet at a slight speed penalty. In purposes in which total lesion size is of greater importance, the mouse and tablet are equally accurate for lesion segmentation.

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B. Informatics in Radiology: Automated Web-based Graphical Dashboard for Radiology Operational Business Intelligence, in **RadioGraphics, the Journal of the Radiological Society of North America,** Paul G. Nagy, Max J. Warnock , Mark Daly, Christopher Toland , Christopher D. Meenan and Reuben S. Mezrich.

RadioGraphics

Informatics in Radiology

Automated Web-based Graphical Dashboard for Radiology Operational Business Intelligence[1]

Paul G. Nagy, PhD • Max J. Warnock • Mark Daly, BS • Christopher Toland • Christopher D. Meenan • Reuben S. Mezrich, MD, PhD

TEACHING POINTS
See last page

Radiology departments today are faced with many challenges to improve operational efficiency, performance, and quality. Many organizations rely on antiquated, paper-based methods to review their historical performance and understand their operations. With increased workloads, geographically dispersed image acquisition and reading sites, and rapidly changing technologies, this approach is increasingly untenable. A Web-based dashboard was constructed to automate the extraction, processing, and display of indicators and thereby provide useful and current data for twice-monthly departmental operational meetings. The feasibility of extracting specific metrics from clinical information systems was evaluated as part of a longer-term effort to build a radiology business intelligence architecture. Operational data were extracted from clinical information systems and stored in a centralized data warehouse. Higher-level analytics were performed on the centralized data, a process that generated indicators in a dynamic Web-based graphical environment that proved valuable in discussion and root cause analysis. Results aggregated over a 24-month period since implementation suggest that this operational business intelligence reporting system has provided significant data for driving more effective management decisions to improve productivity, performance, and quality of service in the department.

Abbreviations: DICOM = Digital Imaging and Communications in Medicine, FTP = File Transfer Protocol, HL7 = Health Level 7, MPPS = Modality Performed Procedure Step, ODBC = Open Database Connection, PACS = picture archiving and communication system, RIS = radiology information system

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[1]From the Department of Diagnostic Radiology and Nuclear Medicine, University of Maryland School of Medicine, 22 S Greene St, Baltimore, MD 21201-1595. Presented as an Informatics Course at the 2008 RSNA Annual Meeting. Received January 5, 2009; revision requested March 5 and received April 6; accepted April 28. R.S.M. is a scientific advisor to MobileAccess Networks; all other authors have no financial relationships to disclose. **Address correspondence to** P.G.N. (e-mail: *pnagy@umm.edu*).

Introduction

The field of business intelligence, also known as business analytics, has demonstrated significant improvements in industries outside of healthcare (1). Business intelligence tools enable management to make more relevant decisions with greater frequency, facilitating smaller course corrections to keep the business improving and minimizing oversights.

Teaching Point

The two principal benefits of a business intelligence solution that can affect the culture of an organization are transparency and fact-based decision making (2). Supreme Court justice Louis Brandeis noted that "sunlight is said to be the best of disinfectants" (3) as a remedy for social diseases. Transparency can be used as a powerful tool to provide accountability and ownership of performance improvements.

A focus on fact-based decision making changes traditional response models based on emotions and anecdotal perceptions of service. Sharing data and analysis is seen as a powerful way to influence other key stakeholders into aligning to a common vision of a problem. Creating an open culture that is willing to take an unwavering look at the "brutal facts" of an organization is seen as a key characteristic of a competitive company (4). Clinical information systems used in radiology today house a treasure trove of operations data that is not currently being used by clinical management to create a culture of quality and enable a more engaged and enlightened management environment.

The need for management reporting in radiology dates back to the 1970s as one of the core components identified in early radiology information system (RIS) implementations. In 1979, Arenson and London (5) described the need for a computer system to provide operations management to perform time-flow analysis to improve efficiency. A RIS provided tabulated reports to be printed out. These would evolve into reports that could be e-mailed for monthly reporting processes.

In 1994, Crabbe et al (6) described a manual extraction methodology for obtaining data from a RIS that provided the means to perform higher-level analysis on data as well as the ability to distribute graphical analysis in the form of Excel files (Microsoft, Redmond, Wash) from a central file server. In 2000, Seltzer et al (7) used a Web site as a digital dashboard to communicate operational parameters. In 2003, our group used automated extraction methodologies to dynamically build Web reporting capabilities for performance and utilization management off a single picture archiving and communication system (PACS) (8).

In this article, we describe a Web-based dashboard that was constructed to automate the extraction, processing, and display of indicators and thereby provide useful and current data for departmental operational meetings. In addition, we evaluate the feasibility of extracting specific metrics from clinical information systems as part of a longer-term effort to build a radiology business intelligence architecture. Specific topics discussed are problems with a paper-based reporting method, data extraction architecture, information visualization, and enabling knowledge discovery.

Problems with a Paper-based Reporting Method

To understand the need for an online dashboard, we first identified the department's many frustrations with the traditional paper-based processes of analysis, reporting, and quality management. Many significant challenges limit the effectiveness of the standard methodology of monthly paper-based reporting.

Teaching Point

The time and effort required to build reports creates a capture latency that diminishes the value of the information as well as the time the organization then has to take action to identify and implement remedies (2).

Teaching Point

Paper-based reporting can answer only a relatively small list of questions that must be identified *before* the monthly (or other periodic) meeting that routinely addresses such questions. This finite list limits the focus in such meetings to the data at hand and prevents any attempt to follow outside data, identify disturbing trends that have not yet become true issues, or delve deeper into operations. When questions are asked that cannot be answered, they are taken "off-line" and answered at the next meeting if remembered at all. This cumbersome and sometimes quite subjective process slows the ability of an organization to respond quickly to events or to plan effectively for change.

Teaching Point

Paper-based reporting lacks the granularity to drill down on a metric and view the original data. The ability to view the actual data from which statistical analyses are derived offers a higher level of confidence in understanding data and making subsequent decisions. It can help detect bias such as skewed distributions or data integrity issues that might affect decisions as well as avoid anecdotal mistrust of the data.

Metrics Selected for Display on the Dashboard

Metric Label	Group	Description
% Outpatient Arrived	Order and arrival	Compliance metric; tracks percentage of time the front desk enters an arrival time for outpatients
Outpt. % Seen < 15 min	Order and arrival	Performance metric; tracks percentage of patients taken back for their examinations within 15 min
Avg PICC Time to Arrival	Order and arrival	Performance metric; tracks average time in hours for placement of a PICC, from the time an order is received to the patient's arrival at the unit for PICC placement
Avg STAT TAT*	Order and arrival	Tracks average time from receipt of a high-priority order to completion of image acquisition
% Outpatient Begin	Image acquisition	Compliance metric; tracks percentage of time the technologists enter a procedure begin time
% Wait > 1 h	Image acquisition	Performance metric; tracks percentage of patients waiting for more than 1 h to be seen
QC Issues	Image acquisition	Tracks number of quality control issues submitted by radiologists (13)†
Image Quality	Image acquisition	Tracks perceived image quality as determined by means of technologist peer review
Repeat Rate	Image acquisition	Tracks self-reported image reject and retake reasons
Undictated > 1 mo	Interpretation	Billing metric; tracks number of studies performed with no report dictated after 1 mo by interventional radiologists
Average C–P (h)	Interpretation	Performance metric; tracks average time in hours from completion of a study to completion of the preliminary report
% Peer Reviewed	Interpretation	Compliance metric; tracks percentage of reports on which a radiologist performed peer review
Res Review Submissions	Interpretation	Tracks the number of resident reports that were discrepant with the attending physician's report
Unsigned > 2 wk	Reporting	Outlier metric; tracks number of unsigned reports more than 2 wk old
Average P–F (h)	Reporting	Performance metric; tracks average time in hours from preliminary report of a study to the time the report is finalized
EPR Ratio	Reporting	Tracks number of formatting errors detected in the final report sent from the speech recognition system
Critical Findings Delivery	Reporting	Tracks number of critical findings documented

Note.—EPR = errors per report, PICC = peripherally inserted central catheter, TAT = turnaround time.
*This metric excludes the emergency department and shock trauma unit, which have embedded imaging modalities.
†Number in parentheses is a reference.

In addition, paper-based reports are usually constrained to those "canned" reports available in the RIS. These predefined reports represent those topics that RIS vendors expected departments to ask for at the time of software development. These topics and the elements reported often prove inflexible to changing business and operational needs. Creating custom reports is often challenging, preventing departments from answering questions and fully understanding their operational data.

The metrics used at the University of Maryland School of Medicine before implementation of our dashboard efforts were similar to those in most academic radiology departments (9–12). We evaluated the elements of the paper-based report to determine the importance and difficulty of acquiring these metrics from clinical information systems in an automated method. The Table lists the metrics used as key indicators in the department on the dashboard. Continuous quality improvement requires the ability to change the metrics on the dashboard as well as the targets for those metrics. The purpose of departmental operational meetings is to identify problems and opportunities to improve performance. As the department improves, metrics can be retired or the goals can be changed. The dashboard must be able to incorporate the moving-target focus of the meeting.

Teaching Point

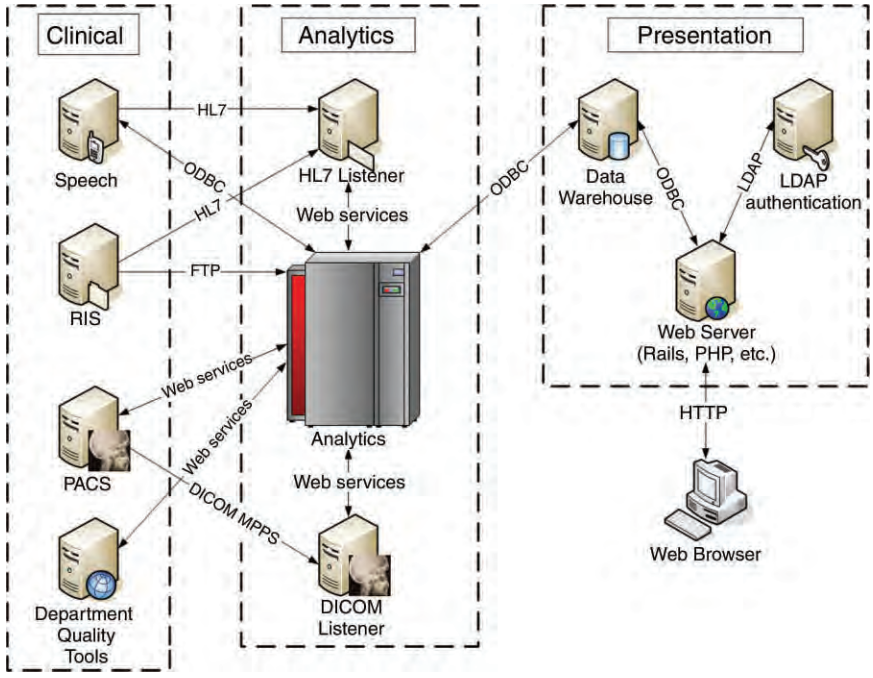

Figure 1. Architecture of the data warehouse infrastructure. Clinical information systems were interfaced using a variety of methods to extract performance and quality indicators. *HTTP* = Hypertext Transfer Protocol, *LDAP* = Lightweight Directory Access Protocol.

Data Extraction Architecture

One of the challenges to providing a comprehensive view of operations is that data are often distributed among several different information systems, each containing only discrete pieces of the work flow. We constructed a platform to collect data from all systems to build a comprehensive view of operations using the MySQL open-source database as the central data repository (14). The key identifier to link the fragments of data together was the unique accession number for each procedure.

Data extraction tools were developed in the Python programming language to acquire operational data from all of our clinical information systems, using standards as well as customized extraction methodologies. We leveraged two powerful open-source tools, the DCM4CHE Digital Imaging and Communications in Medicine (DICOM) archive (15) and the MIRTH Health Level 7 (HL7) server (16). A DICOM repository was created using DCM4CHE to collect DICOM Modality Performed Procedure Step (MPPS) messages automatically routed from a PACS (6.2 IMPAX; Agfa, Brussels, Belgium). HL7 messages of orders and reports were routed from a RIS (IDXRAD 9.0; GE Medical Systems, Fairfield, Conn) to the MIRTH HL7 report repository.

For non–standard-based reporting, the extraction methodology had to be tailored to the type of information and vendor from which the data were derived. Custom reports generated from the RIS using their KBSQL reporting module stored reports in comma-delimited files. An extraction script retrieved those files at regular intervals via File Transfer Protocol (FTP), parsed the information, and uploaded the data into the MySQL database. The PACS was queried using a metadata extraction Web service provided by the PACS to obtain information within the DICOM objects, such as the number of images and the performing physician.

A speech recognition system (RadWhere 2.0; Nuance Healthcare Solutions, Burlington, Mass) provided data via an Open Database Connection (ODBC) with an account restricted to only SELECT Structured Query Language statements for stability and security purposes. Quality tools developed within the department, such as quality control issue tracking, were also incorporated into the architecture of the data warehouse. Because the data warehouse contained personal health information, clinical security precautions defined by the Health Insurance Portability and Accountability Act were necessary, and appropriate security measures were enacted.

The interfaces were developed, specified, and tested over several months. For each interface,

the commercial vendors were consulted and the reporting methods were specified. No development was requested from the vendors. The easiest interfaces to implement were those based on open standards, such as HL7 and DICOM. The FTP interface was straightforward, as prepackaged reports were retrieved via FTP. The Web service interfaces used publicly available application programming interfaces that were published and maintained by the vendors. The most difficult were the ODBC interfaces, which required a special understanding of the vendor's database structures as well as constrained permissions and testing to ensure that our interface did not affect the performance of the clinical system. Figure 1 illustrates the architecture and interfaces employed.

The timing of data extraction depended on how frequently the data were being reviewed and how actionable the information was. The goal was to minimize the capture latency of data acquisition. The main tables of the RIS are extracted every evening into the data warehouse for tracking waiting times, turnaround times, and stat order times. Order and report information via HL7 and DICOM MPPS messages via DICOM come across within minutes from the clinical information systems.

Every hour, a report of undictated studies is pulled from the RIS and fed into a global work list for the department. Identified undictated studies are then queried to the PACS in real time using Web services to determine the number of images on the PACS and the performing physician for interventional studies. This method helps alert staff to studies that were completed but have no images on the PACS. Four times each day, a RIS report is pulled for a list of unsigned reports. Signing physicians are sent a text page via e-mail with the number of unsigned reports by location. This eliminated an inefficient process in which radiologists had to log in to multiple RISs to see whether a report was ready to sign. Integrating an alerting mechanism with a dashboard application is valuable to communicate actionable information and ensure a timely feedback mechanism.

Information Visualization

More than a dozen commercial business intelligence platforms that incorporate information visualization are on the market today. The business intelligence industry is undergoing rapid innovation, with several large vendors with complete solutions and a multitude of smaller vendors with best-of-breed components. The two highest-rated solutions as determined in an industry analysis in 2008 are BusinessObjects from SAP (Walldorf, Germany) and Cognos from International Business Machines (Armonk, NY) (17).

We elected to use a commercial Web-based graphing tool and construct our own Web dashboard because of our phased approach and leverage our experience in Web development. The dashboard grew out of several smaller quality projects started in 2004 to monitor unsigned and undictated reports. The multiple projects needed a roof to house them all for direct access and comparison. Although our platform was developed on open-source technologies, significant investment was required to customize the dashboard to our department.

The Web site was developed using the open-source programming language and application framework Ruby on Rails (18). The Web site used the Ruby ChartDirector imaging library (Advanced Software Engineering, Hong Kong) to dynamically generate graphics on demand as bubble charts, histograms, fuel gauges, time trends, and run charts. When a user requests to load a Web page, the Ruby on Rails framework requests the most recent data from the database, which are rendered into a graphic JPEG file. As the database is updated, those changes are immediately displayed within the graphs. Asynchronous JavaScript enables users to click on areas within the graph to select subregions. This allows users to intuitively drill down through the graphs and explore complex dynamics that can affect operations.

The main-level page with the departmental overview was distributed throughout the department as a Web link and showed all the major indicators as fuel gauges (Fig 2). This provided novel transparencies within the department to help align the focus on areas needing improvement. Thresholds were set for each metric in the quality meetings to define a target zone in green, a warning zone in yellow, and a trouble zone in red. Many of the performance targets were derived from yearly departmental goals and objectives. The fuel gauges provide an easy method to review all the metrics at a glance. Each fuel gauge is linked to detailed analysis on that metric so that users can understand the results more fully.

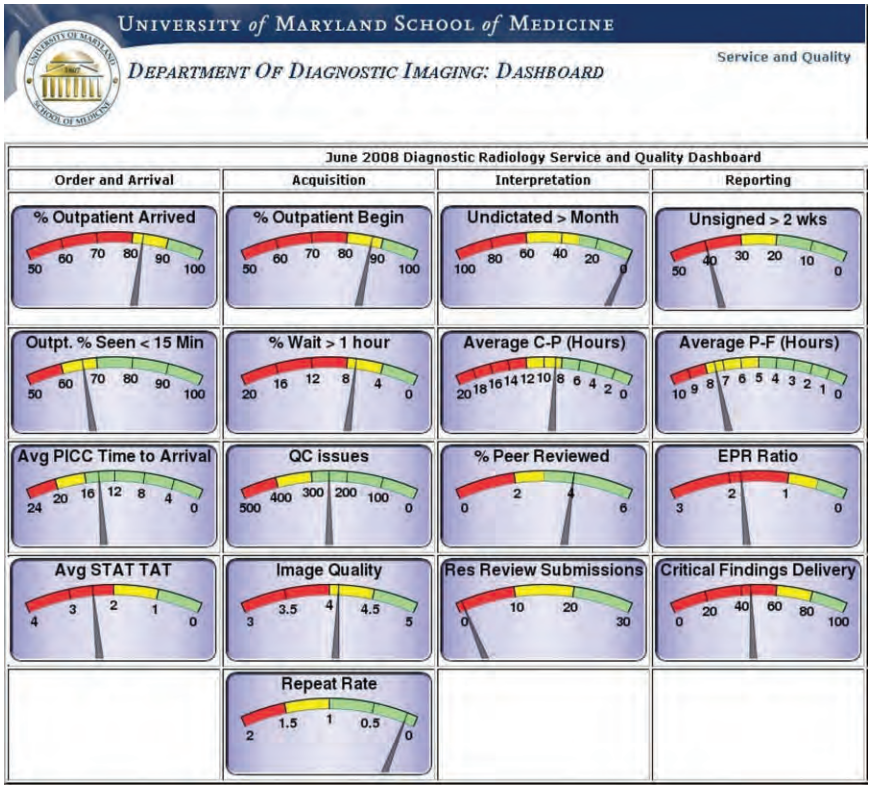

Figure 2. The main page of the dashboard provides an overview of the major key performance indicators. Each gauge is described in the Table. *C-P* = completed study–preliminary report, *EPR* = errors per report, *P-F* = preliminary report–final report, *PICC* = peripherally inserted central catheter, *TAT* = turnaround time.

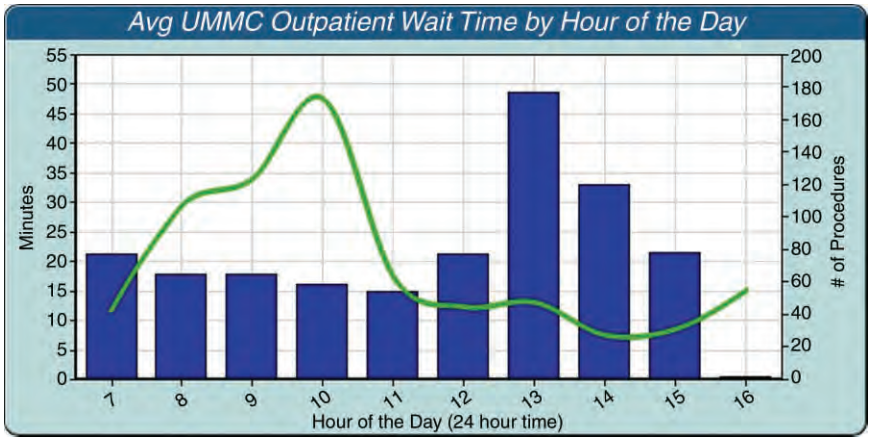

Figure 3. Dual-axis graph shows the average outpatient waiting time for mammography (green line) as a function of the time of day (24-hour clock). Blue bars = patient volume.

A secure log-in is required to access pages that include personal health information. We employed the Lightweight Directory Access Protocol for user authentication and authorization, based out of our PACS. This allowed users to access the dashboard with their PACS log-ins and eliminated the need for separate password management. According to the sensitivity of the data, such as radiologist peer review, data analysis views were restricted to only those staff authorized for management of that metric.

Beginning in July 2006, the dashboard was used as the central focus of our twice-monthly operational meetings. A 60-inch (150-cm) liquid crystal display was installed in the main administrative conference room so that the dashboard could be accessed in real time at all administrative meetings. In addition, staff throughout the department were given access to the site via a Web link.

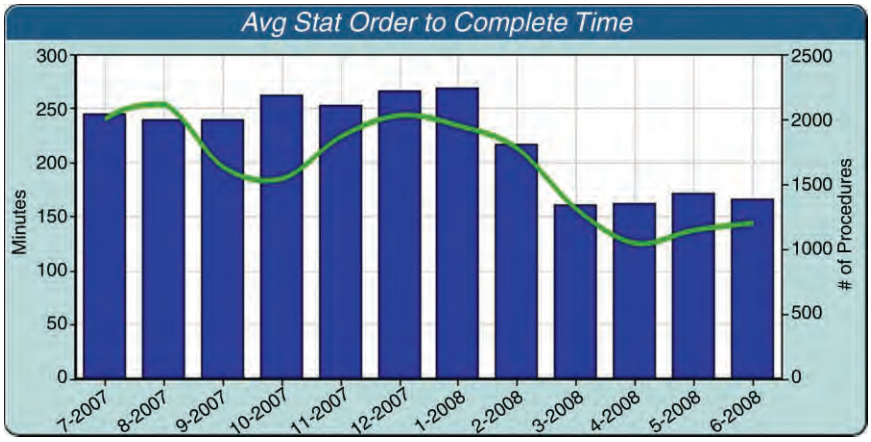

Figure 4. Dual-axis graph shows high-priority inpatient study requests from the time of ordering to the time of procedure completion. Blue bars = monthly volume for one year, green line = average time from order to completion.

Initial results and subsequent experience indicate that the dashboard improved our department's ability to understand performance and enhanced participation in our quality meetings. At the same time, we were able to improve our departmental performance in several key areas. Over a period of 12 months, improvements were observed in the radiology report turnaround time, outpatient waiting times, stat order turnaround times, and quality control resolution times.

It is challenging to attribute improvements to the use of the dashboard. The dashboard drove discussions at the quality meetings and provided context, but it was the management team who used results to initiate additional quality investigations into approaches for improving performance. The dashboard did not enforce change; instead, it enabled improvement by demonstrating problem areas and root causes for those problems and by helping align the efforts in quality initiatives. The dashboard also served as a workbench on which new theories could be tested hypothetically to determine whether they could solve various problems.

Enabling Knowledge Discovery

Each fuel gauge represented a key performance indicator. By clicking on the fuel gauge, the user is taken to an in-depth analysis of that indicator. This analysis attempts to display all the factors that can influence the indicator and may be causes of poor performance. The purpose of the analysis page is to lead a discussion with a successive series of questions that can be answered quickly with a graphic interface. In a traditional paper-based setting, questions frequently cannot be answered immediately and must be followed up in preparation for the next meeting. By providing the ability to sift through data, visualize it both in detail and in a graphical representation, and answer questions immediately, the dashboard not only accelerates the time to fixing problems but also leads a group rapidly through the data discovery process, which aids in their buy-in and accountability for the analysis and results.

Figure 3 is an example of one of the levels of analysis on our dashboard and shows average outpatient waiting times for mammography in minutes (green line, plotted as a function of the hour of the day) and number of procedures (blue bars). This graph shows a steep rise in waiting times from 10 minutes at opening to more than 45 minutes by 10 AM. This is a common type of queuing problem that can be caused by scheduling, staffing levels, room utilization, or examination durations. In this example, the quality committee determined that the high waiting times were the result of scheduling a high number of diagnostic mammography procedures in the morning, requiring more resources and longer individual examination times than did screening mammography procedures.

Figure 4 shows the average time from the ordering of a stat study for an inpatient to the time the procedure was completed. (Emergency department and shock trauma studies were filtered out because both areas have embedded imaging equipment, operate on an almost continuous stat basis, and do not involve hospital patient transport.) The overview graph demonstrates the performance of this indicator (green line) over a period of several months, overlaid with the number of procedures performed (blue bars). Other

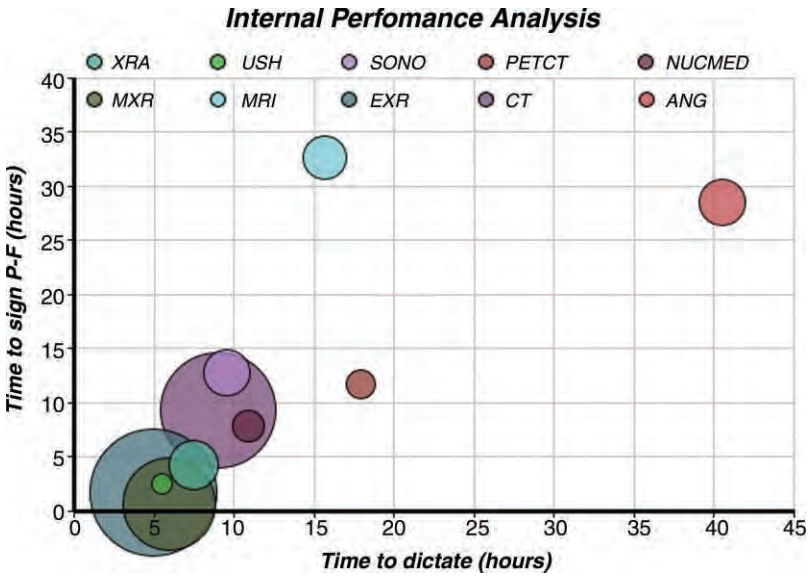

Figure 5. Bubble chart shows radiologists' report turnaround time for 1 month by departmental section. *ANG* = angiography, *CT* = computed tomography, *EXR* = emergency x-ray, *MRI* = magnetic resonance imaging, *MXR* = trauma x-ray, *NUCMED* = nuclear medicine, *PETCT* = positron emission tomography/CT, *P-F* = preliminary report–final report, *SONO* = ultrasonography, *USH* = satellite hospital, *XRA* = x-ray.

graphs tied to this indicator demonstrated dependent factors, such as patient location, time of day, day of the week, requesting physicians, requested procedure, and modality resources. In February 2008, a change was made to the order entry system, with ordering physicians required to enter a pager number to be called back for high-priority orders. This change caused a subsequent drop in orders with a corresponding improvement in response time for ordered studies.

The purpose of data collection and graphical display is to allow viewers to quickly detect trends or dips in service and then be able to zoom in on trouble spots to understand the cause. The process provides an overview of the indicator in a dynamic way that allows a tighter focus on specific factors affecting performance. This allows the user to drill down through the graphs to see the underlying detailed information for each study, thus helping explain specific problems.

Figure 5 is a report turnaround bubble chart displaying the sections within the department. A bubble chart is a useful information visualization tool for displaying three dimensions of data. The x axis represents the average time from the completion of the study to the time of the preliminary report. The y axis is the time from preliminary signing to final signing. Each section is represented by a different color, and the size of each bubble is directly related to the number of procedures that section performed for that month.

Figure 6 is a trending analysis showing departmental radiologist reporting time over 2 years as a percentage of studies in the department that were reported within 2-, 8-, 24-, and 48-hour windows. The timeliness of radiology reporting has received significant attention in the process improvement literature (19,20). Our department has conducted several initiatives to reduce the turnaround time, and the dashboard was able to plot the effects. The department began automatically paging radiologists daily for unsigned reports in March 2005, implemented speech recognition throughout 2006, and in January 2007 instituted a new system to synchronize study status between the RIS and the PACS. A graphical dashboard can act as an instrument on which to conduct experiments in process improvement.

Conclusions

Radiology management is under considerable pressure to do more with less (21). A perfect storm is forming, created by declining reimbursement rates, rising expectations of patients and clinicians for faster turnaround times, and national initiatives to improve the quality in radiology to enhance outcomes. These forces are driving radiology professionals to look for ways to improve efficiency and productivity without sacrificing quality. Business analytics is a proven tool to help a business become more competitive (22).

Using informatics extraction techniques, we were able to capture the majority of indicators routinely used in our quality meetings and drive

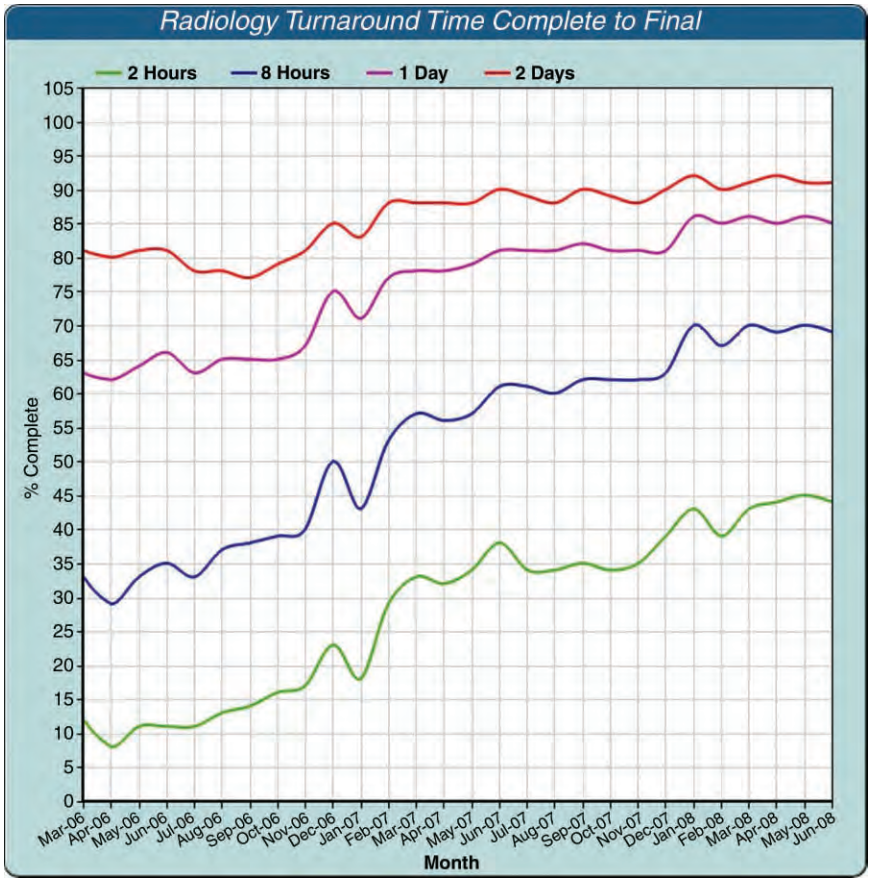

Figure 6. Graph shows the 2-year progression in the percentage of reports that were signed promptly in the radiology department after implementation of automated quality control and dashboarding tools.

the process in a paperless, automated fashion. This was viewed as a significant improvement that made the meetings more effective and provided a better understanding of the operations of the department.

Significant effort was required in extraction of the metrics from clinical information systems. Although some vendors provide reporting packages and a few provide a Web service programming interface, no standard methods have been defined for extracting metrics in radiology. We have added components to our purchase requirements for new clinical information systems that request the vendor to expose internal operational business logic using a service-oriented architecture based on Web services. This allows other systems to gather data for business intelligence applications. We encourage other consumers of clinical information systems to consider their interoperability needs for business intelligence.

For an energized leadership committed to service excellence and quality, a dashboard can be a powerful tool to help improve performance in radiology. Continuous quality efforts are widely recognized as crucial elements in the successful radiology department (23). However, quality committees and leadership too often lack the tools to effectively drive change and remain relevant.

A Web-based graphical dashboard provides a level of transparency of operations to empower effective management. Management in our department found this to be a useful alignment tool by exploring data as a group on a projected screen. Supervisors, section chiefs, and administrators were provided with access to the Web site. Another important benefit has been the reduction in the effort and time previously required to collect and prepare reports.

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Automated Web-based Graphical Dashboard for Radiology Operational Business Intelligence

Paul G. Nagy, PhD, et al

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Page 1898
The two principal benefits of a business intelligence solution that can affect the culture of an organization are transparency and fact-based decision making (2).

Page 1898
The time and effort required to build reports creates a capture latency that diminishes the value of the information as well as the time the organization then has to take action to identify and implement remedies (2).

Page 1898
Paper-based reporting can answer only a relatively small list of questions that must be identified before the monthly (or other periodic) meeting that routinely addresses such questions.

Page 1898
Paper-based reporting lacks the granularity to drill down on a metric and view the original data. The ability to view the actual data from which statistical analyses are derived offers a higher level of confidence in understanding data and making subsequent decisions.

Page 1899
Continuous quality improvement requires the ability to change the metrics on the dashboard as well as the targets for those metrics.

C. Innovations in the Surgical Environment Retreat Agenda

Appendix C. Innovations in the Surgical Environment Retreat Agenda

8:30 Welcome and Introductions, charge to the group Dr. Park
Brief review of ISE history Dr. Park
9:15 Key findings, pre-retreat interviews Dr. Gordon
Discussion of results Dr. Park
10:00 Break
11:00 Discussion
Ranking exercise
12:30 Working lunch
1:30 Work groups (Break out)

1. Governance/Organization
2. Funding
3. Program
4. Research

2:30 Group reports and discussion
3:30 Summary and next steps
4:00 Adjourn

Distinguished Participants in the ISE Planning Retreat

Caroline Cao, MD, PhD Tufts University
LTC Jerome Buller, MD Bethesda Naval
Ken Dobler Ethicon Endo Surgery
Erik Dutson, MD USC Stanford
Robert Foster, PhD US DoD ret.
Dennis Fowler, MD, MPH Columbia University
Ivan George University of Maryland
Toby Gordon, ScD Gordon and Associates / JHU
Greg Hager, PhD Johns Hopkins University
Rosemary Klein, MA University of Maryland
Gyusung Lee, PhD University of Maryland
Reuben Mezrich, MD, PhD University of Maryland
Gerry Moses University of Maryland
Paul Nagy, PhD University of Maryland
Adrian Park, MD University of Maryland
(COL) Ron Poropatich, MD US Army TATRC (Diverted from attending)
Steve Schwaitzburg, MD Cambridge Health Alliance
Richard Satava, MD University of Washington / DoD ret.
Raj Shekhar, PhD Children's Washington DC
Brady Shirley IMD Medical, Inc.
General Fred Smalkin, JD, BG US Army ret.
Russ Taylor, PhD Johns Hopkins University
Yelena Yesha, PhD UMBC (Univ. MD Baltimore Campus)

D. Summation of ISE Expert Workgroups

Summation of ISE Expert Workgroup Activity

The strategic planning group then divided into four discussion panels. Each considered a topic – Program, Funding, Research, and Organization/Governance –in regard to ISE expansion and was charged with bringing back 3 levels—operational; strategic and BHAG—of recommendations.

Program Group (Schwaitzberg - leader; George, Buller, Caban, Dutson)**:**

Strategic: The group suggested that future meetings might incorporate a "resort model" with an aim to ensure pairing of interventionalist and non-clinician. The thought was that the program should be looking to mate with the organization, i.e., as ISE looks to "set the dialogue" the program be developed on the dialogue of the moment. A mix of presenters fluent and expert in the "current dialogue" should be recruited. A specific focus on establishing individual relationships with well-established and exciting innovators such as Steve Jobs, Bill and Melinda Gates, etc. that would result in drawing high caliber (and a large volume of) attendees to ISE events was identified as crucial. Meeting frequency was considered to be tied to funding, but an annual, if possible, event was considered optimal.

Operational: The program committee would, in the main, be responsible for obtaining presenters as well as scouting out and establishing high-level innovative relationships. In order to specifically establish how the next large format ISE program might appear, it was suggested that ISE hold a consensus conference over two days, with one day devoted to clarifying "Vision" and the other to clarifying "Academics." One discussion that ensued in the group meeting was in regard to ISE not being about clinical disease but rather about the environment in which clinical disease is treated; this would be among the types of Issues that would be dealt with at the consensus conference. The group determined that based on the current regulatory and fiscal environment ISE would not offer CME. A side discussion resulted in the suggestion that the organization's title be changed to the Institute of Interventional and Surgical Medicine (IoISM).

BHAG: The group favored a large conference with "big name" speakers injected into the program and a program that is firmly grounded in setting and carrying on the dialogue. Significant discussion (per Dr. Schwaitzberg) centered on holding an ISE equivalent of a TED conference. Essentially, the conference as envisioned by the group is one that generates a large "buzz" *and* large interest *and* a large participant pool, though with a degree of exclusivity.

Funding Group (Yesha - leader; Moses, Taylor and Smalkin)**:**

Strategic: The overall group would recommend, as expected given previously held strategic discussion, the formation of a formal organization to support and extend the ISE conference and to serve as a clearing house for policy development and funding. The need was stated for a small cadre of permanent staff led by an Executive Director to sustain the effort. Major costs would be incurred in regard to the scheduling and conducting of the annual ISE conference. The group approached the issue of fiscal

support with a broad brush, noting that many options should be developed to obtain funding.

Operational: Operational costs and smaller grants will be sought with NIST, TATRC, and AHRQ identified as specific agency targets. Broader funding needs would be approached via direct appeals for donor support, proposals to government and provincial granting agencies, foundation grants, and possible industry sponsorship (The IBM Center for Advanced Studies and also insurance companies were specifically proposed for funding targeting). Establishment of a small cadre of permanent staff led by an Executive Director would serve several functions 1] support of the formal organization, 2] support and expansion of the ISE conference, and 3] coordination of collaborative activities. As broadly and widely as possible, international (beyond North America) people and ideas should be included. We should take advantage of the current national focus on Health IT and try to leverage smart health prevention and prediction with the surgical innovation.

BHAG: The best model for long-term sustainability of ISE may be to create a non-profit organization and later create for-profit company (possibly based at the University) that will operate the non-profit aspect and can also deal with Ventures. Yesha should approach IBM and seek sponsorship for the ISE conference and try to co-locate ISE with CASCON 2011. This year is the 100th Anniversary of IBM, so we may get some more funding and publicity. The event will be in Toronto Nov.2-5, 2011. Another option would be to host the conference in Halifax and ask NSERC for support.

Research <u>Group</u> (Cao - leader; Klein, Hager, Lee, Satava and Shekhar)**:**

Strategic: The ISE will systematically generate innovation. In the near term, the ISE membership (given its combined expertise and brainpower) will work to identify clinical needs. These needs will then be addressed at focused meetings to generate new ideas. We will invite top researchers in the identified areas to these meetings to present their ideas. In so doing, ISE can strategically "harvest technology," vet ideas, and support the feasibility studies and eventual development of these new and emerging technologies. Domain knowledge possession then would be a role (ISE knows how to translate technology into *<u>use</u>*") Initial, seed funding may be provided to the investigators to prototype their ideas. Resources or simulation facilities may also be provided to ensure maximal output in a short time frame to demonstrate the potential of these new ideas. Intellectual Property (IP) becomes a significant issue in any discussion of research; among the issues are "invention disclosure" and "public domain." Any intellectual property will belong to the investigators. ISE will not own any IP. ISE should, in Cao's terms, consider "Partnering for Intellectual Energy."

Operational: ISE can leverage its mandate of creating physician-driven/ physician-centered needs-driven innovation into partnership with other professional groups, especially the engineering profession (e.g., IEEE, HFES, IEA, etc.). This will allow ISE to become the focal point of a network of professional associations, facilitating cross-society pollination and collaboration, and ultimately being the beneficiary of the research efforts. Going forward ISE needs to take into account the question "Who is the group you're pitching to?" and it needs a person or team to drive this project, much as MMVR is TATRC- and DARPA-driven. ISE also needs one success story showing how the ISE model in regard to a demonstrable pilot study works. The ISE Conference of the future was described as a venue "to harvest ideas w/ a package to be bought." The Conference would also serve to bring together thought leaders and innovators from different

disciplines to brainstorm, come up with a concept, develop a pathway, realize a prototype. Work would be published, a web site maintained, and new intellectual opportunities - Systems-Oriented Concept or End-to-End Holistic – created. It was also suggested that ISE could offer workshops of the type that were focused such as the Hopkins Summer Workshop Series where one thing is worked on and where an idea can be scrutinized by a panel of experts and that could be tied into an organization such as MMVR (it was suggested that ISE could offer surgical training workshops, supportable by TATRC conference monies ($15 to 20,000 for brand-new interesting ideas).
BHAG: The question is can ISE shepherd a project from conception to clinical implementation by removing all obstacles such as funding, clinician acceptance, regulatory requirements, etc. (Fairly early on the point was made that the ISE group -- while "not capable of the 'full research process'" -- could harvest technology components with an emphasis on emerging technology and basic simple components.) Another BHAG noted by Satava was that ISE would eventually face operationalization in a number (3 or 4) of hospitals.
Research Pillars

The 4 or 5 pillars for ISE research cannot be replaced but need to be re-defined as they can be misleading. Most of the research issues for ISE are cross-cutting, i.e., they result from a combination of several pillars, not least of which is a human factors pillar. In the absence of a better nomenclature, use of the terminology "pillars" serves as a categorizing device for workshops' and/or conferences' themes.

Research Approach

The OR is a complex socio-technical environment, utilizing a synthesis of technologies that include everything from small mechanical devices to complex information systems, from techniques to processes. Therefore, we recommend a systems approach which takes into account any themes represented as research pillars with a focus on innovation in the OR (such as ISE developing a new paradigm in surgical approach).

Organization/Governance Group (Fowler - leader; Dobler, Mezrich, Park and Shirley)**:**
Strategic: *Structure:* The group agreed unanimously that we need a formal organization to define the mission and execute the goals of ISE. The concept is that the ISE would be a consortium (or at least consortium-like) and would include constituents from academia, industry, the military, other government entities, and other organizations. The latter could include organizations as diverse as IEEE and AORN. The formal structure would likely include officers, a board, committees, and a hired executive director to operationalize both the structure and function of the ISE. Ideally, the board would consist of someone sympathetic to the needs/goals of at least one of the multiple, diverse constituent groups.

Audience: The group spent more time discussing the audience than any other topic. Ultimately, we agreed that the audience might include providers (both individual and institutional), medical/surgical societies, technology startups, big industry, NIH, AHRQ, payers, and policymakers.
Mission and Goals: Based on the thought that the design process is flawed, ISE should strive to facilitate innovation through support of new ideas and also facilitate their development through the applied research and commercialization phases of technology development.
Operational: *Tactical:* The committee structure of ISE should be developed in response to the goals of the organization. Working committees would design and deliver on each goal of the organization. This was actually started in the retreat with the Program and Funding committees.
BHAG: ISE should approach the Institute of Medicine and seek to become their arm engaged in overseeing innovation and improvement in the interventional cycle. By combining the expertise of the ISE membership with the political clout and *gravitas* of the IOM, the impact on the intervention cycle in both the near- and long-term future could be very significant.